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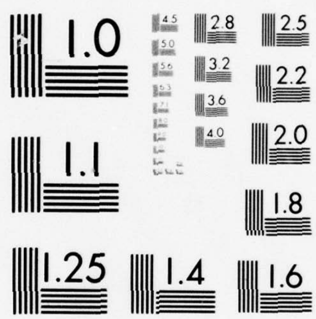

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INVESTIGATION OF THE TECHNICAL AND OPERATIONAL FEASIBILITY OF USING A VHF DATA LINK FOR TRANSMISSION OF INTERMITTENT POSITIVE CONTROL (IPC)

Volume I

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D. A. Swann
K. F. Peter

August 1977

FINAL REPORT

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FEDERAL AVIATION ADMINISTRATION
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16. Abstract

This report presents the results of an investigation of using a VHF Data Link to transmit collision avoidance commands to aircraft operating in the National Air Space. Operational scenarios are developed and system capacity evaluations are performed to establish the operational feasibility of the concept.

Identification of potential concepts considered feasible generated the design and cost development of the avionics required in support of the prepared operation of IPC on a VHF Data Link.

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SUMMARY

ARINC Research Corporation is under contract to the Federal Aviation Administration (Contract DOT-FA76WA-3788) to assist in the development and evaluation of technical and cost factors that will affect the FAA policy regarding the Collision Avoidance System (CAS) as a national standard. One effort under this contract was an investigation into the technical feasibility of utilizing the VHF data link as a means of transmitting Intermittent Positive Control (IPC) commands to aircraft and the development of the cost of the avionics required by such a system.

The IPC capability was developed in conjunction with the Discrete Address Beacon System (DABS); however, the IPC concept can be implemented on other data links meeting minimum requirements.

This report was prepared in response to the Department of Transportation's review of Upgraded Third Generation Air Traffic Control System Developments and is not intended to advocate IPC implementation by means of a VHF data link. Rather, it provides data for use in assessing the merits of this approach.

Three potential IPC data link concepts were identified: a dedicated VHF data link for IPC traffic only, a combined company communications and IPC VHF data link patterned after the airline industry ACARS data link, and a combined FAA ATC tactical and IPC VHF data link. However, the latter was considered impractical for implementation in the near future and was not evaluated in detail (only a theoretical capacity analysis appears in Appendix A to the report). The other two concepts were evaluated for throughput capacity as a function of various traffic densities and percentages of IPC implementation. Traffic densities were developed with the aid of the 1982 Los Angeles Basin Standard Traffic Model, considered representative of a dense environment during the deployment and implementation of IPC. Three implementation strategies were defined from these two concepts (i.e., all aircraft using Concept 1, all aircraft using Concept 2, and a hybrid in which general aviation aircraft use Concept 1 and air carriers use Concept 2) and evaluated in detail to demonstrate the technical feasibility of VHF IPC data links.

The dedicated VHF data link was examined for various modes of channel management, with varying data rates and equipment characteristics, to evaluate the effect on system performance of a system constrained by existing avionics performance parameters and by new avionics manufactured according to existing technology. It was found that all dedicated VHF data link performance options considered in this report could transmit IPC separation assurance commands to aircraft populations defined by the 1982 Los Angeles Basin Model.

The concept of implementing IPC using the ACARS data link was similarly evaluated, considering parameters similar to those of the dedicated VHF data link but assuming that only the commercial air carriers and selected high-performance general aviation aircraft would have the full-capability ACARS system. Under this implementation strategy the majority of general aviation aircraft would require a newly designed mini-ACARS terminal to receive IPC commands. When the IPC communications were combined with the expected heavy volume of company communications on the ACARS data link, it was concluded that ACARS can handle only a low initial implementation load, e.g., 45 percent of the 1982 Los Angeles Basin traffic.

The hybrid IPC implementation strategy was found to be able to handle 1982 Los Angeles Basin Model IPC communications. The ACARS system could easily handle the additional IPC communications to the commercial air carrier aircraft, and the dedicated IPC system could easily handle the IPC communications load to the remaining aircraft. However, the procedural problems of implementing a hybrid system were not addressed, and these could be significant.

The IPC avionics required to support the options of a dedicated VHF data link and the ACARS data link were developed and cost-estimated under the assumption of large production quantities. Table S-1 presents the per-aircraft cost of equipment acquisition for a single system for four versions of a dedicated VHF data link. The costs reflect the expected selling price of avionics to the three communities of interest: the air carriers, high-performance general aviation, and low-performance general aviation. Table S-2 presents similar avionics cost data for IPC using the ACARS data link.

While the primary concern was the evaluation of VHF data links that could handle near-term peak traffic levels, the ability of the various concepts to handle long-term traffic levels was also examined in the light of data from the 1995 Los Angeles Basin Model. The results of the analyses show that, for long-term implementation, the capacity to handle the IPC communications requirements through the 1990s could be provided by either a multi-channel (4-channel uplink) dedicated VHF data link with altitude discrimination or a hybrid version of the ACARS data link (air carriers using ACARS and general aviation aircraft using dedicated VHF data link).

Table S-1. COST SUMMARY FOR DEDICATED VHF DATA LINK				
Equipment	Configuration Option Costs (Dollars per Aircraft)			
	Single-Channel Uplink Only	Single-Channel Duplex	Four-Channel Uplink Only	Four-Channel Duplex
Air Carrier and Selected Military Aircraft				
Avionics Unit	1679	2373	1901	2660
IPC Display	152	152	152	152
Antenna*	180	360	180	360
Total	2011	2885	2233	3172
High-Performance General Aviation				
Avionics Unit	2183	3085	2473	3458
IPC Display	197	197	197	197
Antenna*	240	480	240	480
Total	2620	3762	2910	4135
Low-Performance General Aviation				
Avionics Unit	722	1015	887	1232
Antenna*	16	32	16	32
Total	738	1047	903	1260

*Data from manufacturers' published price lists,

Table S-2. COST SUMMARY FOR IPC USING ACARS	
Equipment	Avionics Cost per Aircraft (Dollars)
Air Carrier and Selected Military Aircraft	
Signal Processor	1055
IPC Display	152
Total	1207
High-Performance General Aviation	
Signal Processor	1371
IPC Display	197
Total	1568
Low-Performance General Aviation	
Mini-ACARS with Display	593

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) is aware of the direct correlation between the growing aircraft population, and the ever-increasing difficulty in providing separation assurance and collision avoidance through the current ATC system. Efforts to develop an improved national standard to provide separation assurance have resulted in the investigation of both air-derived and ground-derived collision avoidance concepts. Programs such as the Beacon-Based Collision Avoidance System (BCAS), the Selective Address Beacon (SAB), the VHF Data Link, and the Discrete Address Beacon System with Intermittent Positive Control (DABS/IPC) are under continued exhaustive investigations to determine the involvement of each in future ATC plans and operations.

As a result of the above concerns, the Office of System Engineering Management (OSEM) of the FAA has engaged ARINC Research Corporation (Contract DOT FA76WA-3788) to perform a series of investigations and to provide separate reports on the findings associated with each of these investigations. This contract directs ARINC Research Corporation to analyze and develop the technical, operational, and economic feasibility of implementing certain surveillance and separation assurance concepts in the expected aircraft population of the 1980s and beyond. The system investigations to be performed span the range from comprehensive, long-term solutions to partial, short-term solutions to provide improved surveillance and collision avoidance.

1.2 CONTRACT SCOPE AND OBJECTIVES

The overall investigative effort involves many of the alternative ideas for upgrading the present air traffic control system and entails the development and analysis of performance and cost factors in the following five task areas:

Task I - Avionic Alternatives for Selected ATC System Developments

Task II - Selective Address Beacon System

Task III - VHF Data Link

Task IV - DABS/IPC Impact on Air Carriers

Task V - ARINC Interfaces with FAA Communications Modernization Program

This report documents the results of Task III.

1.3 PROJECT OVERVIEW

The objective of Task III is to determine the technical, economic, and implementation factors of a VHF data link as an interim, near-term method for transmitting collision avoidance commands to aircraft. To accomplish this goal, it has been necessary to determine the operational feasibility, evaluate the technical feasibility, and develop cost estimates for the avionics supporting the data link. Because there are a number of VHF data link alternatives available for consideration, the characteristics of three plausible VHF data link systems were examined to develop the data on which to base the discussion and analysis of the data link concept. The data link systems considered are a dedicated IPC VHF data link, a combined IPC/ATC VHF data link (considered because of the existing ATC communications link), and an IPC service using a non-FAA VHF data link (considered because of the ongoing development of a well-defined commercial air carrier VHF data link).

Table 1-1 summarizes this approach by identifying the major tasks and subtasks used to derive and justify the conclusions of the report regarding the operational capability and cost effectiveness of the IPC VHF concept.

1.4 ORGANIZATION OF THE REPORT

The eight chapters of this report address each of the tasks and subtasks of Table 1-1.

Chapter Two outlines the technical approach developed by ARINC Research, provides details on three representative communications system concepts of an IPC VHF data link, and discusses the potential implementation impact on the user activities. These concepts are the basis for the analysis in this report.

Chapter Three discusses the data link characteristics of the communication system concepts. Possible message formats for each type of data to be transmitted are developed, with consideration given to existing ground and avionic equipment characteristics. The equipment characteristics are used in the analysis of the communications concepts to ensure compatibility between candidate equipments and the proposed VHF data link characteristics.

Chapter Four details traffic density and message-arrival-rate data and presents a mathematical model of the VHF data links developed to allow an analytical determination of system channel capacity. Results of the model exercise yield channel utilization, mean waiting time, and mean number of messages waiting for each traffic type on the data link.

Table 1-1. MAJOR TASKS OF VHF DATA LINK STUDY

Identification of Plausible IPC VHF Data Link Scenarios

- Identify near-term VHF data links of possible use to IPC
- Develop plausible data link configurations worthy of further investigation

Technical Feasibility

- Determine technical requirements of data link
- Determine data transfer formats
- Determine types of data to be transmitted
- Develop an analytical model applicable to all VHF data links being considered
- Exhibit the capacity of each data link system concept through use of the data link model

Operational Feasibility

- Determine the level of avionic modification necessary
- Examine initial impact of IPC on ground facility operations
- Examine the implementation feasibility

Economic Evaluation

- Develop cost of IPC displays
- Estimate cost of equipment for commercial aviation use
- Estimate cost of equipment for general aviation use

The impact of implementing the system concepts discussed in Chapter Two is examined in greater detail in Chapter Five. Avionic configurations are presented for each system concept and aviation class as appropriate. Chapter Six presents cost estimates of the system configurations exhibited in Chapter Five, while Chapter Seven discusses possible data link implementation capability.

Chapter Eight summarizes the results of the investigation and presents specific conclusions derived from the analysis performed.

Supporting technical details, as well as references, are presented in the appendixes.

CHAPTER TWO

KEY FACTORS IN THE VHF DATA LINK EVALUATIONS

The VHF radio navigation band used to support aircraft operations is a candidate means for introducing IPC on the air traffic control communications networks, or a new network dedicated exclusively to separation assurance. Each of these network concepts is examined in this chapter, and operational system concepts that can be readily implemented are developed in sufficient detail to permit evaluation of the capability for providing IPC separation assurance. In subsequent chapters, the costs of avionics required to implement the feasible data link concepts are developed to identify the expenditures that will be required to provide IPC separation assurance via VHF data links to high-performance air carrier aircraft and limited-performance general aviation aircraft.

2.1 PHILOSOPHY OF APPROACH

The use of the VHF aeronautical radio band to provide a data link for IPC commands to aircraft is considered a near-term, interim solution to collision avoidance pending implementation of the DABS/IPC concept. The near-term implementation goal, together with the need to provide IPC at low cost to all interested aviation communities, establishes the guidelines and approach for evaluating the VHF data link system alternatives.

The study provides the avionics costs associated with implementing an IPC VHF data link by several different alternatives. The economic analysis is based on avionic equipment design concepts developed as part of this study that relate design and implementation complexities to total cost. Three IPC VHF data link communications system concepts are defined to develop preliminary avionics designs. These concepts are representative of system configurations and channel-management techniques often discussed in association with a VHF data link and are considered typical of the technical complexity and economic commitment involved in implementing any near-term VHF data link. Each concept identifies the channel-management techniques, ground-facility management responsibilities, and message types to be carried on the IPC link in sufficient detail to permit analysis of the required channel capacity of each.

It is emphasized that the IPC system concepts and accompanying equipment representations presented herein do not reflect final system designs and that further analysis could result in improved designs. They are, however, definitive enough to be used in estimating VHF data link costs for comparison with the costs of other separation-assurance concepts.

Message-encoding techniques, message formats, and data-transfer formats are used in conjunction with ground and aircraft VHF equipment characteristics to determine the technical feasibility and channel capacities of each of the scenarios proposed. The data link characteristics are also used in the development of IPC equipment designs.

A data link performance model was required to establish the overall design parameters of each IPC system concept (e.g., receiver turnaround times and system channelization requirements) and ensure the feasibility of the alternatives. A mathematical model based on queuing theory was therefore developed; it was exercised with a near-future aircraft traffic environment to establish channel capacities of the various communications system concepts. Probable message-arrival rates and avionic equipment capabilities were generated for the model from a combination of current FAA predictions and ATC operating procedures. The results of the model exercise were channel-utilization factors, mean service times, mean waiting times, mean number of messages waiting, and uplink channel delay times between generation and receipt of IPC messages.

Specific system designs, including detailed parts lists, were developed for each of the system concepts; parts costs were identified and combined with labor cost elements to obtain the production costs associated with IPC avionic equipment for each IPC system concept. These costs, together with the implementation impact on potential users and the performance predicted by the analytical model, were examined to determine the most cost-effective approach to providing IPC through the use of a VHF data link.

2.2 DEVELOPMENT OF REPRESENTATIVE IPC VHF DATA LINK SYSTEM CONCEPTS

Near-term implementation of IPC commands in the VHF aeronautical band can be achieved either by developing a totally new VHF data link or by modifying an existing or planned VHF data link. There is no data link currently in use on the VHF aeronautical band; however, some non-FAA enterprises are considering the implementation of ground-air VHF data links. This analysis investigates as one of the IPC system concepts the priority ordering of IPC commands through modification of such a non-FAA data link. This alternative offers the potential for a low-cost IPC data link through the sharing of non-FAA data link equipment. However, the shared-system approach could involve operational problems. Therefore, new data links embodying IPC must also be considered.

The development of a totally new VHF data link for IPC use provides the analysis with the system concepts of either a dedicated data link or a data link shared by other, yet-to-be-automated FAA communications traffic. A dedicated IPC VHF data link would be an effective method of providing IPC to virtually all user communities. Its implementation would be totally independent of the development of devices and data links unrelated to the IPC system, with the obvious advantage of providing a link free of competition and interference due to other message traffic. The alternative concept of transmitting IPC commands on a VHF data link handling other FAA services is, of course, completely compatible with ground station management and operational procedures of the current ATC system.

The following IPC communications system descriptions identify, for each of the communications concepts, the channel-management technique, ground-facility management responsibility, message types to be carried on the link, and requirements for aircraft participation in the IPC system. Since the IPC concept is the source for much of this information, this concept is discussed first.

2.2.1 IPC Concept and Assumptions Used in the Study

The development of the IPC concept is based on the goal of implementing a totally automatic ground-based collision avoidance system. Through the IPC concept, separation assurance can be provided to both IFR and VFR aircraft by issuing brief, easily interpreted collision avoidance commands on an as-needed basis. The IPC concept requires the development of improved surveillance-data processing techniques and conflict-prediction algorithms. However, this study focuses on the data link aspects of IPC and is not concerned with ground processing elements. The IPC system should require only minimal action by the pilot (e.g., little or no frequency retuning) to receive the IPC commands.

To provide the aircraft with collision avoidance maneuvers, a data link is needed to transmit the IPC commands, including some form of unique aircraft addressing. The data link must be capable of providing a time-responsive and reliable channel for ground-to-air communications. It is assumed in this study that either the aircraft's unique (ground-assigned) transponder code or airframe registration number is available for use by the IPC system as an aircraft address.

Current IPC algorithms are based on providing aircraft with IPC commands approximately 30 seconds prior to a potential collision situation. The data link that provides these commands to the aircraft without significantly diminishing this warning time will be considered time-responsive. Delays of up to 2 seconds between the generation and receipt of an IPC command are assumed to be tolerable.

IPC link reliability must be high to ensure that no erroneous maneuvers are initiated by aircraft. The required level of communications reliability can be obtained through the use of forward-error-detection techniques or automatic technical acknowledgments by the aircraft in response to uplink IPC commands.

Pilot-initiated digital replies, serving to inform the ground facility of the pilot's intention to comply with the recommended IPC maneuver, are not clearly defined as an IPC algorithm requirement. Because there is controversy over pilot participation, the study considers both data links which make provisions for such replies and those which do not. This issue is viewed as separate and distinct from communications reliability.

The following sections develop the IPC VHF data link communications system concepts that provide the basis for the analysis in the remainder of this report.

2.2.2 System Concept 1 - IPC Using a Dedicated VHF Data Link

System Concept 1 is based on the development of a digital data link dedicated solely to IPC use. Such a system would be completely under the control and management of FAA personnel and procedures.

Uncertainty over the type or necessity of a reply to an IPC uplink message makes it necessary to examine the impact of both one-way operation (ground to air) and two-way operation (duplex: ground to air, air to ground). Under the assumption that a reply is not necessary or that verbal communication of the pilot's intent to the air traffic controller is sufficient, the dedicated data link can be configured as a one-way channel (ground to air only). Such a data link would optimize the time for uplink message transmission, secure from interference or interruption by other types of message traffic. Repetitive transmissions, composed of the aircraft's unique address, the IPC command, and other overhead data link characters, would be employed to ensure maximum reliability of data transmission.

A two-way (duplex) dedicated data link is also examined to satisfy the requirement of receiving a digital confirmation of the uplink command. Whether the response is automatic or manual, the objective is to advise the IPC computer directly of the transmission integrity of the command or the pilot's compliance with the command. It is also considered necessary that the response be kept on a separate frequency so that, as in the one-way concept, the time available for uplink transmissions will be maximized. Repetitive transmissions of the commands (a necessity in the one-way case) are eliminated, since retransmission of uplink commands can be controlled by the digital response received by the ground facility.

To prevent unaddressed aircraft from initiating avoidance maneuvers and addressed aircraft from executing incorrectly received commands, an error-detection technique will be included in the IPC transmission.

Transmission sites for an IPC dedicated data link would be located to provide coverage equivalent to the ground radar station generating the raw surveillance data for the area.

As a system that is designed as backup to the interaction of air traffic controller and pilot, the IPC system should be independent of human intervention when not actively displaying a collision avoidance maneuver. Therefore, the nationwide use of a single frequency or single pair of frequencies on a one way or duplex IPC data link is investigated. Should a one uplink-channel system be found inadequate to handle the expected IPC traffic load, an alternative solution to the problem of minimum human intervention and capacity limitation on the uplink channel is investigated.

An option to either the one-way or the duplex data link is the concept of segmenting the airspace horizontally (by altitude), rather than vertically (by geography or radar coverage). This horizontal division of airspace can be accomplished automatically, thereby maintaining the concept of a system independent of human intervention during normal (nonconflict) operations. By examining traffic densities and patterns, a minimum number of altitude bands composed of various flight levels can be determined. Each of these bands would have a unique frequency assigned nationwide. Each altitude band (frequency) would contain significantly fewer aircraft than the total number in the geographic area visible to ground radar or transmitters, thereby increasing the total capacity of the system. Automatic retuning of IPC dedicated VHF receivers as an aircraft climbs or descends through altitude bands could be accomplished by using the encoding-altimeter data (a requirement placed on all IPC recipients). To compensate for the tolerance of the encoding altimeters, the altitude bands could be overlapped. It is thus implied that aircraft traversing the overlap between altitude bands would have IPC commands transmitted on both frequencies to increase the probability of receiving the message.

2.2.3 System Concept 2 - IPC Using the Automatic Communications Addressing and Reporting System (ACARS) VHF Data Link

ACARS is a digital VHF data link currently being investigated by the commercial air carriers for implementation on the existing ARINC* VHF radio network system. This non-FAA network system provides ground/air/ground voice communications coverage over large areas of major intercity flight paths. It is scheduled to operate in both en route and terminal areas on a single nationwide frequency and is designed to accommodate the ordinarily high volume, fixed-format messages of company communications.

Each network is composed of favorably sited, unattended, remotely controlled VHF stations (transmitters and receivers), which are linked by telephone lines extending from one or more ARINC Communications Centers. Technical acknowledgments are used by ACARS to verify error-free receipt of messages. These acknowledgments control the retransmission of both ground- and air-originated messages. The remote sites are discretely addressable by the ACARS for transmission and reception of messages. Ground-to-air contacts require ACARS to choose the optimal site for broadcast to the aircraft. If the aircraft does not respond, ACARS transmits from, and attempts to receive an acknowledgment through, each surrounding

*Aeronautical Radio, Inc.

remote site. When a downlink message is transmitted by an aircraft, it is received by multiple remote sites in the area. ACARS is programmed to reject multiple identical messages by recognizing a message-sequence code contained in each transmission. Channel management of ACARS, although initially planned to operate in an aircraft demand mode, can be implemented through ground-controlled polling of aircraft.

The ACARS/IPC data link configuration on commercial aircraft would make maximum use of existing ACARS equipment. Aircraft not privy to ACARS message traffic but desiring IPC capability would have to obtain a "mini ACARS/IPC" system capable of processing only IPC traffic. Ground facilities of the ARINC network would have to be modified to receive the IPC message over land lines, recognize its priority, and place it at the head of the line in a priority store-and-forward message buffer device. Replies to IPC commands, if necessary, would be on the same frequency as the uplink traffic and be given the highest priority of all downlink messages and a lower priority than any uplink message. Possible benefits of this scenario are the use of an existing VHF ground network that is converting to digitized data in the near term, good coverage, one nationwide frequency, and acceptance by many potential users.

2.2.4 System Concept 3 - IPC Using a Digital FAA ATC VHF Data Link

The FAA does not utilize a digital data link for any of the services it provides. Initial investigation into digitizing current ATC voice communications (References 1 and 2) has resulted in the classification of ATC information into ATC Tactical or ATC Record communications. ATC Tactical communications are classified as heading, altitude, VHF voice frequency, and airspeed data traffic. This traffic is easily digitized, and some analysis has been performed on data link characteristics of an ATC Tactical Display (References 2 and 3). ATC Record message characteristics are longer and less time-critical than ATC Tactical traffic, contain alphanumeric and symbolic characters, and utilize either fixed or free message format. Examples of ATC Record traffic are terminal information, IFR clearances, weather data, and other similar ATC functions. (This information is not as easily digitized or implemented as the ATC Tactical.)

The concept of an ATC data link is seen as a major undertaking involving a spectrum of technical, operational, and Governmental control and policy problems. Because of the magnitude of the financial and technical effort involved in the transformation from voice to digital transmission, and the current lack of effort in the area, this data link is not considered to be a feasible candidate for implementation within the period of interest. Therefore, the body of the report does not address this concept. Further discussion of this concept relating to the system configuration or channel capacity is presented in Appendix A.

2.3 POTENTIAL IMPLEMENTATION STRATEGY

In light of the foregoing considerations, there are several methods by which IPC can be provided to the various airspace users on the basis of the three communications system concepts. Table 2-1 defines the three possible schemes, or cases, for providing IPC commands to commercial air carriers (CA), general aviation (GA), and nontactical military aviation (MIL).

Table 2-1. IMPLEMENTATION CASES

Case	CA	GA	MIL
1	Dedicated IPC*	Dedicated IPC*	Dedicated IPC*
2	Modified ACARS	ACARS compatible	ACARS compatible
3	Modified ACARS	Dedicated IPC*	Dedicated IPC*

*Note: Both one-way and duplex options will be considered.

In Case 1 (based on Concept 1 of Section 2.2.2) all aircraft would receive IPC commands transmitted from FAA ground stations through essentially *similar avionics configurations.* The commercial air carriers would be required to procure equipment for an IPC data link in addition to ACARS data link avionics. Most general aviation and all applicable military aviation would have to add a second (or third) VHF receiver or transceiver.

Case 2 (based on Concept 2 of Section 2.2.3) would allow the ACARS users to implement an IPC data link by modifying ACARS equipment. However, it would force general and military aviation aircraft to procure potentially expensive and overly sophisticated equipment to be compatible with the powerful ACARS encoding technique but not be able to use its expanded capability. For this implementation scheme, it is presupposed that there are operational and political agreements between the FAA and ACARS users to "piggyback" their network with higher-priority IPC messages to themselves and a large community of non-ACARS members.

Case 3 employs the favorable factors of Cases 1 and 2 for each user community. It permits commercial air carriers to modify the ACARS data link to receive IPC commands -- thereby avoiding the added cost of a second set of data link avionics demanded in Case 1. This case also permits general aviation and applicable military aviation to procure avionics equivalent to Case 1 configurations, resulting in significantly simpler (therefore, lower-cost) equipment than in Case 2. The ground-facility impact on the implementation of Case 2 is a minimal IPC algorithm modification concerning the recognition of the class of aircraft (GA or CA) in conflict and then formatting and routing the IPC command as discussed for the dedicated or ACARS shared link as appropriate.

The remainder of this study develops and analyzes the economic and technical characteristics of the IPC VHF data link system concepts defined in this chapter. The feasibility of implementing the three concepts will be determined from the results of the technical and economic investigation of each communications system concept.

CHAPTER THREE

DATA LINK CONSIDERATIONS

This chapter is a discussion of the various characteristics of the communications data associated with each of the data link system concepts. Proposed concepts and philosophies are examined to develop the data characteristics and message formats for IPC only and combined IPC/ACARS traffic. The data-transfer formats have been selected on the basis of available modulation techniques, bit rates, and bandwidths that are compatible with current ground and avionic equipments. The results of an investigation of equipment factors typical of both ground and avionic equipment that directly affect data link performance, together with a discussion of the impact of IPC system implementation on current ATCRBS ground interrogators, are also presented.

3.1 REVIEW OF CHARACTERISTICS

A review of the characteristics of the IPC system and the ACARS message formats was conducted prior to the development of the alternative VHF data links for IPC.

3.1.1 IPC System Characteristics

The IPC system is to be a nonredundant back-up to the Air Traffic Controller's safe handling of aircraft. The transmission of an IPC command to an aircraft indicates that a potential for collision exists and that the collision will occur in a predetermined time. The collision avoidance command is an emergency communication requiring immediate attention and compliance. By necessity, then, the commands must exhibit the following characteristics:

- They must be uniquely addressable to specific aircraft.
- They must be brief, easily recognized, and easily implemented by the pilot.
- They must contain an error-detection technique adequate for preventing incorrect or unnecessary maneuvers by the addressed aircraft.

Two aircraft identification techniques are available: the assigned transponder code setting and the aircraft registration number. Assigned transponder codes and the aircraft registration numbers are both visible to the Air Traffic Controller via his radar screen and recognized by the ATCRBS computer system. Therefore, either of these two addresses can be readily used by an IPC system.

Brief, easily recognized collision avoidance commands that are readily implemented by the pilot were developed and used in the production of the display depicted in Figure 3-1. The X-shaped and arrow-shaped symbols, when activated in the proper sequence, inform the pilot which maneuvers are not permissible and which are required to avoid a collision or near miss. For example, if the upper arrow (a) and the right X (f) are lighted, the pilot should initiate a climb and should not turn to the right.

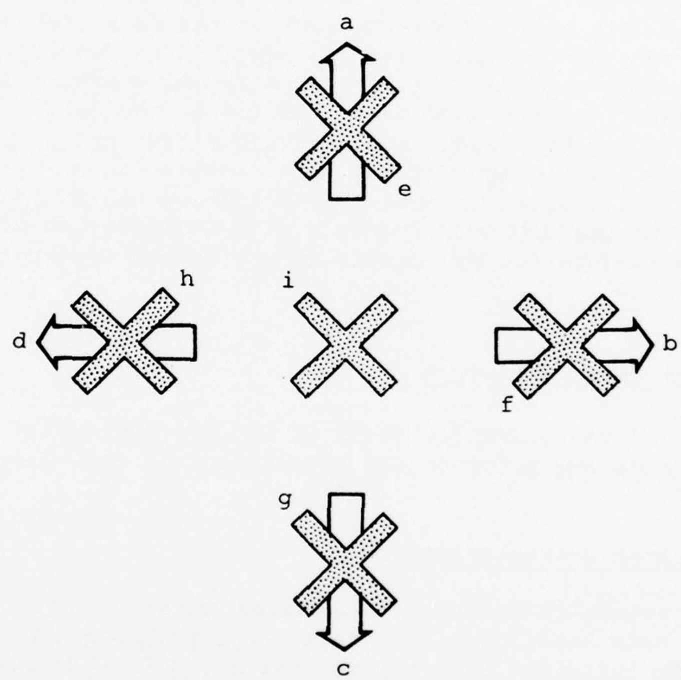


Figure 3-1. IPC DISPLAY

No specific error-detection or -correction techniques are defined as a part of the basic IPC concept. Such a technique is mandatory to ensure the detection of transmission errors at both the ground facility and on board the aircraft. The error check by the avionics must be configured to ensure that only properly received messages are displayed to the pilot.

3.1.2 ACARS Data Characteristics

The ACARS concept was developed by Aeronautical Radio, Inc. to enable current company-oriented voice traffic to be digitized and transmitted to and from aircraft via VHF data link.

Message types intended for transmission over the ACARS data link include departure/arrival reports, ETA reports, GMT clock updates, and automatic "Out-Off-On-In" sensor reports. The ACARS description (Reference 1) sets forth provisions for an Optional Auxiliary Terminal (OAT) to provide the ACARS data link with additional capability. The OAT can vary in complexity from a small character display to an electronic switching device for utilization by a diversified source of terminals. The ACARS communications volume, message content, and message lengths change as the OAT device changes in function. Therefore, the ACARS message has been designed to exhibit the following characteristics to accommodate all proposed functions of the ACARS data link:

- The ACARS message must contain the aircraft's unique address for recognition purposes for both receipt and transmission of messages from ground facilities and from the aircraft.
- The code-set must provide for full alphanumeric data.
- The ACARS message must provide for error-detection and technical-acknowledgment functions.
- The ACARS must provide the ability to accommodate the long, unformatted alphanumeric text arising from implementation of the OATS into ACARS.

To generate sufficient coding for the special functions and abbreviations used in company communications, a bit length of 8 bits per character (7 bits plus parity) is required by the ACARS system. Selective addressing techniques under consideration for the system are the use of the aircraft registration number or the airline flight number of the aircraft; both require the character flexibility provided by an 8-bit character. The message is composed of characters coded according to the seven-unit convention specified in ICAO Annex 10.* Appended to the message is a block check sequence composed of 16 bits which do not comply with this coding convention and are distinguished from communications control by their relative position.

The format of Table 3-1 applies to both air-to-ground and ground-to-air messages.

Further information concerning ACARS message, data, and display characteristics is presented in Reference 4.

*International Civil Aviation Organization.

Table 3-1. ACARS MESSAGE FORMAT	
Function	Number of Characters
Pre-Key	16
Bit Synchronization	2
Character Synchronization	2
Start of Heading	1
Mode	1
Address	7
Technical Acknowledgment	1
Label	2
Start of Text	1
Text	220 (maximum)
Suffix	1
Block Check Sequence (BCS)	16 (bits)
BCS Suffix	1

3.2 IPC MESSAGE FORMATS

The IPC message formats developed in this study represent two extremes. The dedicated IPC message format is a brief structure designed to provide maximum information with minimum transmitter use. The ACARS/IPC message format is more complex and time-consuming because of the concessions that must be made in a multi-purpose data link. These message formats are used in Chapter Four for analysis of the system capacity inherent in each proposed concept.

3.2.1 Dedicated IPC Data Link

Decisions regarding an IPC message format applicable to a VHF data link were not made prior to this study. The format developed for use by IPC on the dedicated VHF data link is constructed to satisfy all of the IPC characteristics identified in Section 3.1.1. Efforts have been made to maximize the information content of each transmitted bit. The major items contained in the format are the IPC text, the address technique, and the error-detection technique.

The IPC text is composed of thirteen data bits and is designed so that the nine display arrow and X symbols can be controlled by a string of nine bits. The symbols on the display are correlated to locations in the bit field to provide control of commands to each symbol. Active commands are

transmitted by positioning a "1" in the correlated location. Passive commands are transmitted by positioning a "0" in the correlated location. The tenth bit activates the flashing of all energized symbols. The eleventh and twelfth bits as a pair provide a test capability and display control. The transmitting of a "01" or "10" in the test field overrides all bit patterns and activates all lights -- steady if "01", or flashing if "10". Neither of these tests will erase a previously displayed IPC message from the display memory. Bit patterns "00" or "11", sent during operational modes, direct cumulative or noncumulative activation of the IPC symbols. Transmission of a "1" in the 13th bit location actuates an audible signal alarm for 3 to 5 seconds, after receipt, to attract the pilot's attention to the display. The IPC text bit assignments are summarized in Table 3-2.

Table 3-2. BIT ASSIGNMENTS FOR IPC TEXT TRANSMISSION

Text Bit Number	1 2 3 4	5 6 7 8 9	10	11 12	13
Function or Symbol Assignment*	a b c d (arrows)	e f g h i (X's)	Flash	Display Test and Control	Audible Alarm

*Symbols a through i correlate with the symbol positions of Figure 3-1.

Further detail and development of the IPC text format can be found in References 3 and 5.

To assure the delivery of the IPC text to the selected aircraft, the text is included in the message format structure of Table 3-3. In addition to the pre-key, synchronization bits, and other necessary overhead data link functions, the IPC text is preceded by twelve binary digits. These digits are used for encoding the assigned transponder code of the aircraft as a unique address*. The transponder code has been selected rather than the aircraft registration number because the code requires fewer data bits than required to encode the alphanumeric characters of registration numbers. Following the IPC text, a 9-bit error check sequence is inserted. The block check sequence (BCS) is derived by treating the message information binary digits as coefficients of a polynomial, G(x). This polynomial is divided by a predetermined polynomial, P(x); the remainder of this operation is R(x), the block check sequence. The sum of G(x) and R(x) is the bit sequence transmitted to the aircraft and subsequently divided again by P(x) (by the avionics) to verify error-free receipt of the message. The polynomial chosen, together with the number of error-checking digits, will detect two single bit errors; all burst errors of nine or fewer consecutive bits, 99.6 per cent of the burst errors of 10

*This assumes that operational procedures to guarantee the availability of unique transponder codes for IPC users can be developed.

Table 3-3. SHORT-MESSAGE FORMAT FOR IPC DEDICATED DATA LINK		
Function	Number of Bits	Comment
Pre-Key	20	Each "pre-key" character should consist of all binary ones with all parity rules waived. During the "pre-key" transmission, receiver AGC settling and transmitter power output stabilization will be achieved.
Bit Synchronization	9	Transmission required to enable resolution of bit ambiguity (transmitted bit stream 001110010).
Start of Heading	1	Indicates the start of the message and initiates the BCS (transmission of a binary 1).
Aircraft Address	12	For assigned transponder codes -- 4 sets of 3 binary digits each.
Technical Acknowledgment	2	Functions of this group of bits will include the ACK/NAK or WILCO/UNABLE replies.
Start of Text	1	"0" for messages without text, "1" for messages containing text (used only if response is composed of ACK/NAK or WILCO/UNABLE).
Text	13	See IPC text discussions (Table 3-2).
Suffix	1	The end of text will be indicated by a bit pulse of "1".
Block Check Sequence (BCS)	9	The BCX is initiated by, but does not include, the Start of Heading bit, and is terminated by and does include the suffix bit. A BCS of 9 bits is transmitted following the suffix bit. These 9 bits are the remainder of the following division: $\dfrac{\text{(A polynomial, in x, derived from the primary digits of the message)}}{P(x) = 1 + x^4 + x^9}$ They are used as reference bits in an error-detection process based on the division of the equivalent polynomial representation of the received message by P(x) in the receiving terminal. This error-detection process controls generation of the technical acknowledgments ACK/NAK and display of the received message (Reference 17).
BCS Suffix	7	The BCS suffix will enable the last bit of the BCS to be decoded.

consecutive bits, and 99.8 percent of longer burst errors. Further details of the theory and methodology of this error-detection technique are contained in Reference 6, together with the initial theorems and references to justify the detection capability of the polynomial chosen.

Data link air-ground replies, initiated either manually or automatically in response to IPC commands, can be coded by use of the same message format. Since the IPC display is updated only upon receipt of an error-free message (as determined by the BCS), manual response to the command need only inform the ground facility of the pilot's intent to comply. This is accomplished by transmission of his address and a "Wilco" or "Unable to Comply" indication, automatically formatted and transmitted after the pilot's response is registered on the display. Automatic responses transmitted entirely without human intervention and regardless of other manual replies can be configured to achieve either of the following two alternatives: (1) a short verification -- by transmission of a technical acknowledgment (ACK/NAK) -- that the IPC command was or was not accepted by the BCS; or (2) a transmission of a message of equal length to the uplink IPC message composed of the technical acknowledgment and the uplink message itself. This combination will indicate the command received and whether it was accepted as a valid error-free message.

3.2.2 ACARS/IPC Data Link

To enable the ACARS/IPC data link system to operate with a maximum of common equipment logic, the IPC message format must employ the same message address technique, overhead structure, and code as ACARS. Therefore, the 37-character overhead defined in Table 3-1 will be combined with the 13-bit IPC message of Table 3-2. Thus the IPC message format on the ACARS data link is considerably longer than the IPC message format defined in Table 3-3. Because the ACARS modem is character-synchronized, for convenience the IPC text length should be extended to 16 bits (2 characters) by the addition of three bits. Through the use of the label characters of the ACARS message format, the IPC commands can be encoded to indicate to the avionics the receipt of a high-priority message and its internal routing. The transmitted value of these two characters in this situation will also signal the ACARS system to defer attempts by the ACARS modem to decode the IPC text.

3.3 EXISTING EQUIPMENT CAPABILITIES

An examination of the capabilities of existing equipment was conducted to determine if a VHF data link could be implemented with the equipment currently in use by the FAA and the aviation community. The equipment capabilities explored form the basis for choosing an appropriate modulation technique and bit rate for a near-term data link.

3.3.1 Ground Equipment

The VHF ground equipment of interest is typified by the equipment in use for air traffic control and airline company communications.

Transmitters are capable of a power output of 50 watts amplitude modulation with a continuous duty cycle. The units can be operated at any frequency within the 116-152 MHz band by insertion of the proper crystal. Narrowband voice modulation (300 to 3,000 Hz) can be transmitted and a majority of the transmitters have provision for wideband transmission (100 to 20,000 Hz). The carrier rise time is under 50 milliseconds (ms) for voice or data transmission.

Ground receivers typically can operate on any of the 25 kHz channels in the 116-152 MHz band by insertion of the proper crystal. Most of the equipment is capable of receiving either voice or data transmissions. Voice bandwidths are generally 300 to 3,000 Hz, while the data bandwidth may extend from 300 to 25,000 Hz. AGC attack times for the ground receivers are typically less than 50 ms, and the sensitivity of the receivers is approximately 3 μV (open circuit) for 10 dB signal plus noise/noise ratio -- (s+n)/n.

3.3.2 Avionics

Both general aviation (GA) and air carrier (CA) avionics are of interest. The CA equipment is representative of the capabilities that can be obtained from sophisticated avionics, while the GA equipment is representative of the capabilities which can be obtained when cost is a major design constraint.

3.3.2.1 Air Carrier

Air carrier avionic equipments are built to specifications established by the Airline Electronic Engineering Committee. Thus the VHF avionics specifications for each carrier are very similar to those of all other carriers.

For VHF communications, the air carriers use transceivers that are capable of tuning to any of the 720 25-kHz channels in the 118 to 139.975 MHz VHF communications band. Transmitter power output is typically 30 watts amplitude modulation with a continuous duty factor. Provisions for both narrowband voice (300 to 3,000 Hz) and wideband data (300 to 20,000 Hz) are incorporated in most CA transceivers. The carrier rise time and AGC attack time are characteristically less than 50 ms. Receiver sensitivity is approximately 3 microvolts (μV) (open circuit) for 10 dB (s+n)/n.

The air carriers also use high-quality VHF navigation receivers for receiving VHF omni-range (VOR) and instrument landing system localizer (ILS-LOC) signals. These receivers have receiver characteristics similar to those of the VHF transceivers but have no data link provisions.

3.3.2.2 General Aviation

General aviation VHF equipment capabilities are more limited than those of air carrier equipments. The GA avionics do not normally include provision for data link operations.

VHF transceivers are used for communications. The equipment is capable of receiving and transmitting narrowband amplitude-modulated voice (300 to 3,000 Hz). The transmitter power output is characteristically 20 watts or less, and the equipment is rated for operation at less than 100 percent duty factor. Receive sensitivity for the GA avionics is approximately 3 μV for 6 dB (s+n)/n.

Measurements by the FAA (Reference 7) on three modern GA transceivers indicated that the GA equipment had carrier rise times under 50 ms and AGC attack times less than 100 ms. On the basis of these measurements, the FAA concluded that two of the three GA transceivers were suitable (with some audio modification) for use in data links at a rate of 4,800 bits per second.

The general aviation VHF navigation receivers used for VOR and ILS-LOC reception might also be used to implement an uplink-only data link. The specifications for these receivers are similar to those for the VHF communications transceivers.

3.4 DATA-TRANSFER FORMAT

Development of an IPC data link that can be implemented in the near future requires the use of an existing data link or the development of a new data link with characteristics that are compatible with existing equipment technology. The most important data link characteristics affecting VHF equipment design are bit rate and modulation type.

3.4.1 Bit Rates

A bit rate of 2,400 bits per second was selected to develop a data link that would be compatible with the capabilities of all ground equipment and a majority of the avionic equipments discussed in Section 3.3. This bit rate is compatible with the narrowband voice audio circuits in existing equipment. A bit rate of 4,800 bits per second was selected as characteristic of a higher-capacity data link. This rate is compatible with ground and air carrier equipment but is at the upper limit of capability of existing general aviation equipment. A data link study by the National Aviation Facilities Experimental Center (Reference 7) has shown, however, that a number of the existing GA designs can be modified to support a data rate of 4,800 bits per second. This data rate should not present a problem in a future GA design.

3.4.2 Modulation Type

Of the many modulation types that might be used -- including pulse amplitude modulation (PAM), pulse position modulation (PPM), and minimum shift keying (MSK)* -- differential frequency shift keying (DFSK) was selected for purposes of this study since it has been demonstrated in the VHF band and is being implemented in ACARS at a rate of 2,400 bits per second.

The DFSK modulation is characterized by shifting between two baseband frequencies, with one frequency equal to the data rate and the second frequency equal to one-half the data rate. The presence of a half-data-rate tone indicates a bit change from the previous bit, while the presence of a data-rate tone indicates no bit change. Phase continuity is maintained throughout the transmission, as illustrated in Figure 3-2. The information represented by the waveform may be either of the two data streams (A&B) shown below the waveform. The transmission of DFSK requires the use of a fixed "character sync" sequence, which allows the receiver to determine the value of the first data bit.

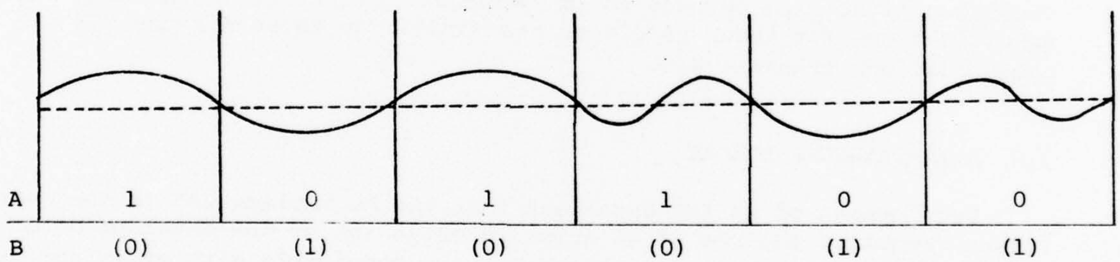


Figure 3-2. DFSK SIGNAL DESCRIPTION

In this study, the 2,400-bit-per-second data link uses baseband frequencies of 2,400 and 1,200 Hz and the 4,800-bit-per-second data link uses baseband frequencies of 4,800 and 2,400 Hz.

3.5 GROUND INTERROGATOR IMPACT

A ground-based separation-assurance system must have the ability to predict the occurrence of a potential conflict and to identify the aircraft involved so that they may be given instructions. It should be noted that improvement of the Air Traffic Control Radar Beacon System (ATCRBS),

*Flight tests by the FAA (Reference 8), using FAA and air carrier equipment, have deomonstrated MSK operation at 2,400 and 4,800 bits per second with an average error rate near 5×10^{-5}.

possibly using monopulse or selective addressing techniques, is required to provide this information.

With the present ATCRBS, the ground interrogators receive identity and altitude information in the form of a digitally coded transmission from an aircraft equipped with an ATCRBS transponder and encoding altimeter. Identity replies (mode A) and altitude replies (mode C) received by one or more ground interrogators are fed into a computer, which compares the position of each reply with previous replies to develop the position, altitude, velocity, and transponder code identity of the aircraft. Therefore, all the information necessary to identify a potential conflict between mode C aircraft is available in the computer and can be related to the assumed transponder code "address" for the aircraft.

In this study, it is assumed that the ground-based surveillance system will have been sufficiently improved to support IPC operation. Therefore, improvements to the surveillance system are not directly addressed in the remainder of this report.

CHAPTER FOUR

DEVELOPMENT OF IPC HARDWARE PERFORMANCE REQUIREMENTS

The performance requirements (i.e., data rates, transmitter/receiver turnaround times, and channelization requirements) for the various IPC alternatives are developed in this chapter on the basis of an examination of system capability as a function of the alternative performance characteristics. These requirements are utilized in the subsequent chapters to develop the hardware designs and system costs.

The analysis process followed in this chapter is depicted in Figure 4-1. Alternative performance parameters (e.g., data rates) are defined for the various IPC concepts. By means of a channel-capacity model, the communications characteristics (i.e., channel utilization and uplink delay time) are computed for each of the alternative performance parameters. The computed communications characteristics are then compared with the communications characteristics desired for satisfactory IPC system performance to determine which of the alternative performance parameters would be most appropriate. One set of performance parameters is then established as the minimal set of parameters required for the subsequent hardware design and cost analyses.

The communications capacity model is described, the desired communications characteristics are defined, and the calculated communications characteristics are presented for each of the alternatives. The performance requirements resulting from analysis of each of the concepts are summarized at the end of the chapter.

4.1 AIRCRAFT DENSITY

This section presents a standard aircraft traffic model and, in combination with some assumptions concerning ATC operations, derives population-distribution data for use in an analytical communications capacity model.

4.1.1 Los Angeles Basin Standard 1982 Traffic Model

MITRE Corporation, under contract to the Office of Systems Engineering Management (OSEM) of the FAA, developed a model based on actual 1972 air activity in a 60-nautical-mile radius about the Los Angeles International Airport (LAX). An extrapolation to 1982 was made by using FAA estimates of the

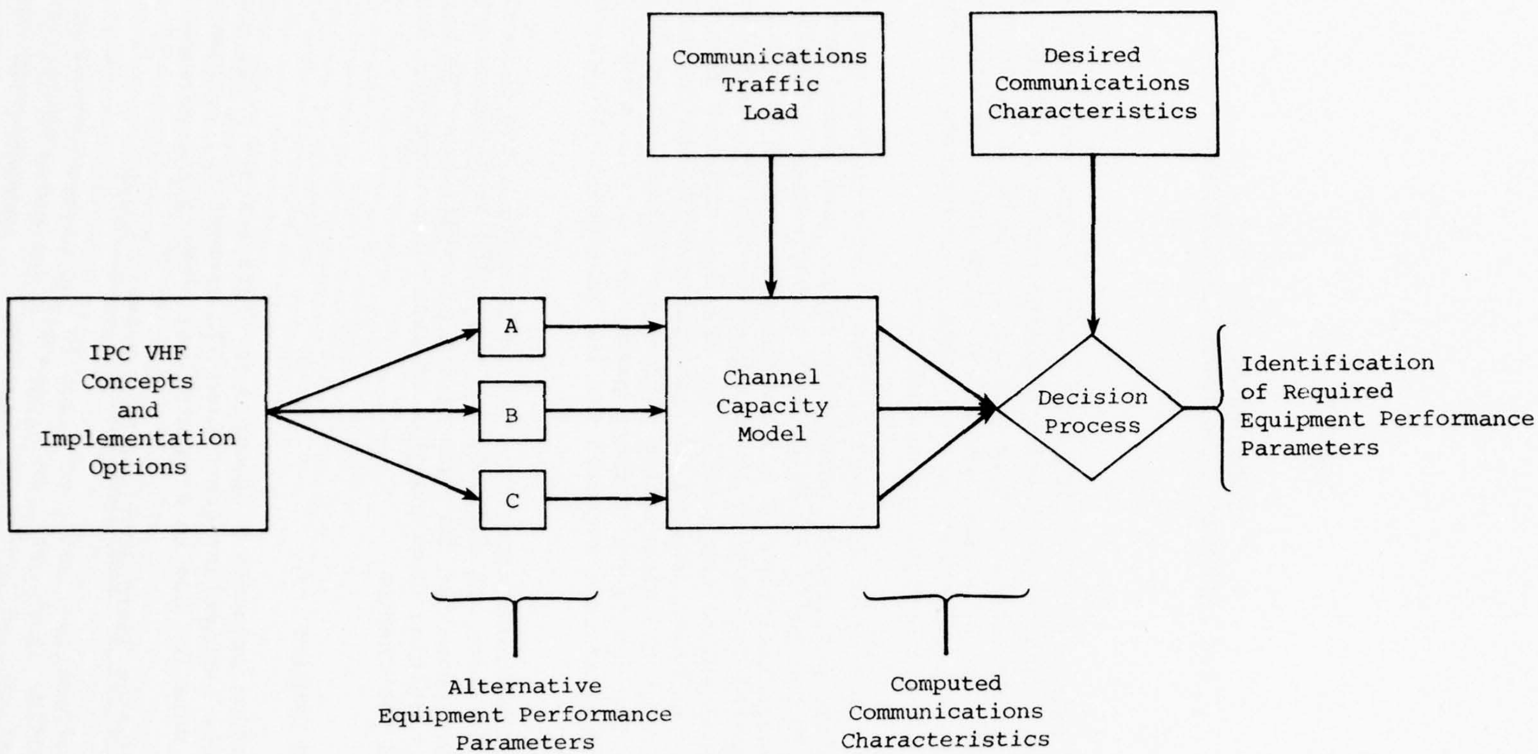


Figure 4-1. DEVELOPMENT OF HARDWARE PERFORMANCE REQUIREMENTS

growth in various categories of aircraft. The additional traffic was then distributed along present air routes to increase aircraft-density factors. (Details of the model derivation are provided in Reference 9.)

The results of the model exercise indicate that in 1982 an expected peak of 806 aircraft of various types is distributed within a 60-nautical-mile radius of LAX. Table 4-1 shows the relative distribution of aircraft and their location (altitude and downfield distance) from LAX.

Table 4-1. DISTRIBUTION OF LOS ANGELES BASIN TRAFFIC FROM STATISTICAL MODEL

Number and Types of Aircraft (A/C) at Different Altitudes						
DRD* 0-10	DRD 10-20	DRD 20-30	DRD 30-40	DRD 40-50	DRD 50-60	Totals
Altitude above 15,000 feet MSL						
0 A/C	2 A/C: CA-1 MIL-1	4 A/C: CA-3 MIL-1	6 A/C: GA-1 CA-4 MIL-1	3 A/C: CA-2 MIL-1	1 A/C (MIL)	16 A/C: GA-1 CA-10 MIL-5
Altitude between 10,000 and 15,000 feet MSL						
1 A/C (GA)	4 A/C: GA-2 CA-1 MIL-1	3 A/C: GA-1 CA-1 MIL-1	6 A/C: GA-1 CA-5	1 A/C (GA)	1 A/C (GA)	16 A/C: GA-7 CA-7 MIL-2
Altitude between 5,000 and 10,000 feet MSL						
22 A/C: GA-21 CA-0 MIL-1	52 A/C: GA-50 CA-1 MIL-1	52 A/C: GA-50 CA-1 MIL-1	25 A/C: GA-23 CA-1 MIL-1	18 A/C: GA-16 CA-1 MIL-1	9 A/C: (GA)	178 A/C: GA-169 CA-4 MIL-5
Altitude below 5,000 feet MSL						
79 A/C: GA-74 CA-4 MIL-1	190 A/C: GA-183 CA-4 MIL-3	145 A/C: GA-139 CA-3 MIL-3	111 A/C: GA-109 CA-1 MIL-1	56 A/C: (GA)	15 A/C: (GA)	596 A/C: GA-576 CA-12 MIL-8

*DRD = downfield radial distance from Los Angeles Airport in nautical miles.

Key: GA - General Aviation; CA - Commercial Aviation; MIL - Military Aviation

The population classifications included in the model and summarized in Table 4-1 are as follows:

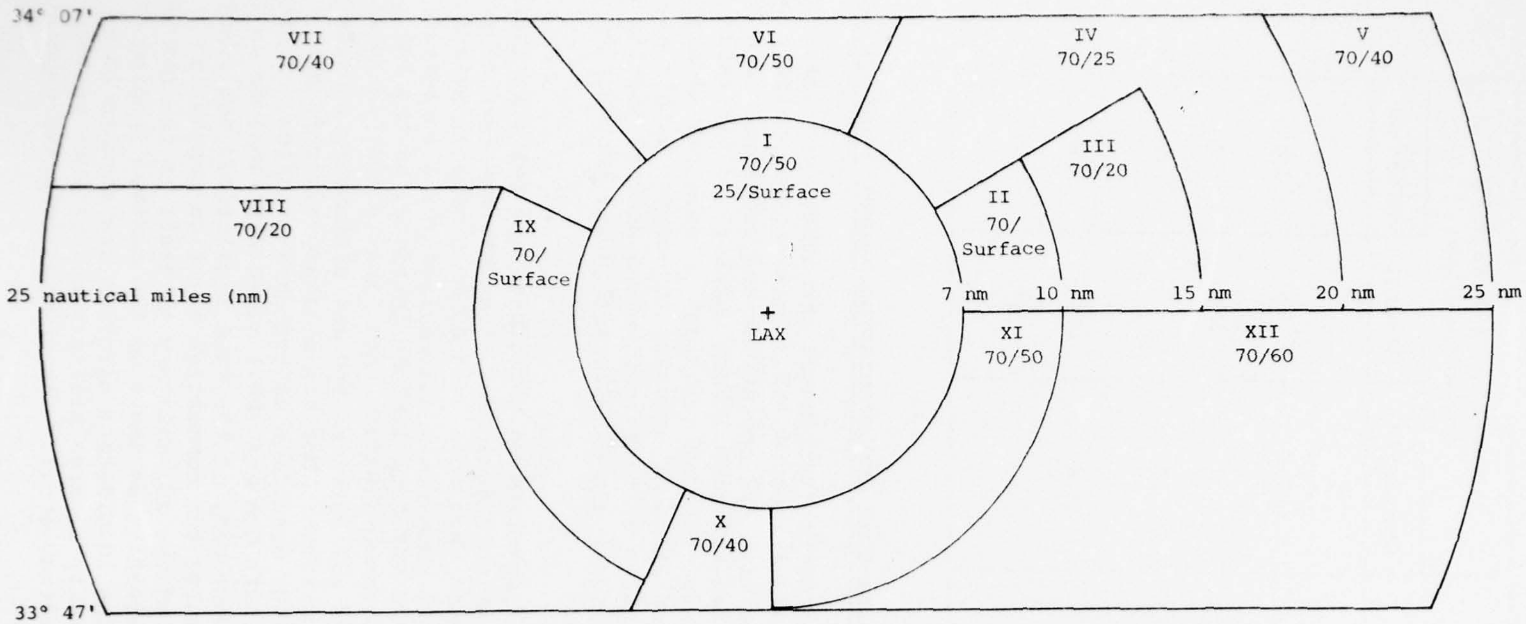
- Commercial Aviation (CA) - defined as air carriers holding a Certificate of Public Convenience and Necessity issued by the Civil Aeronautics Board to conduct scheduled services over specified routes and a limited number of nonscheduled operations.
- General Aviation (GA) - extending from the large, pure-jet cargo fleets, through executive and corporate aircraft, to air taxis and privately owned pleasure aircraft.
- Military Aviation (MIL) - including all military transports and other nontransport DoD aircraft.

The distribution of traffic from this model is needed to simulate the level of air traffic operations envisioned as typical for the 1980s. This level can be directly related to the amount of routine ATC communications, company communications of commercial air carriers, and the need for emergency separation-assurance communications. Therefore, the total message volume of any message type under consideration can be estimated by multiplying a unit aircraft message rate by the number of aircraft capable of receiving or currently participating in that class of communications. To determine the unit message rates, as well as the number of aircraft available for receipt of and the number participating in a particular class of communications, the traffic distribution of Table 4-1 must be further refined. The first refinement is the identification and distribution of aircraft contained within the LAX Terminal Control Area (TCA).

4.1.2 Aircraft Distribution in Los Angeles Basin and Terminal Control Area (TCA)

Figure 4-2 closely approximates the spatial and maximum/minimum flight-level restrictions of the actual TCA of Los Angeles International. The accompanying distribution of aircraft types by sector was derived by using the statistical information in Table 4-1, recognizing a high concentration of commercial and military aviation will exist along arrival and departure routes. In accordance with normal flight procedures, a maximum of 76 aircraft in the TCA are assumed to be either arrivals or departures. Of these 76 aircraft, 57 are assumed to be general aviation, the remainder being composed of military and commercial aviation. All traffic above 10,000' MSL* is assumed to be en route IFR aircraft. The 323 general aviation aircraft below 10,000' MSL and outside the TCA are of various classifications and are discussed in Section 4.1.3. The remaining general aviation aircraft are assumed to be in VFR Highways within the Los Angeles Basin. Table 4-2 shows the traffic distribution resulting from this first series of assumptions.

*Mean Sea Level.



Aircraft Type Distribution by Sector													
Type Aircraft	Sector Number												Total by Type
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
GA	34	4	5	34	18	9	30	63	11	3	10	20	241
CA	2	1	1	1	2	0	0	4	1	0	0	0	12
MIL	1	0	1	1	1	0	0	2	1	0	0	0	7
Total Aircraft within TCA	37	5	7	36	21	9	30	69	13	3	10	20	260

Figure 4-2. ASSUMED LAX TERMINAL CONTROL AREA

Table 4-2. ASSUMED TRAFFIC DISTRIBUTION OF LOS ANGELES BASIN TRAFFIC MODEL			
Airspace	Number of Aircraft by Aviation Class		
	Commercial	General	Military
TCA (260 Total Aircraft)			
Arrivals and Departures	12	57	7
Other Aircraft within TCA	-	184	-
En Route (32 Total Aircraft) (over 10,000' MSL)	17	8	7
Mixed (333 Total Aircraft)	4	323	6
VFR Highways (181 Total Aircraft)	-	181	-

4.1.3 Assumptions Concerning Data Link Implementation Versus Aviation Class

The location and type of aircraft distributed throughout the Los Angeles Basin were developed in Sections 4.1.1 and 4.1.2. This section relates pertinent equipment characteristics with ATC operations and procedures and FAA estimates of aircraft avionics capabilities. Each category of aircraft (commercial air carriers, military, general aviation) is examined separately, with a discussion of the implementation of avionics to support either an IPC VHF or ACARS data link. The results of this section are used to justify the examination of discrete percentage levels of aircraft in the Los Angeles Basin as IPC- or ACARS-equipped.

Although the commercial air carriers do not constantly retrofit their aircraft with state-of-the-art avionic equipment, they are expected to possess a higher quality of equipment than that used by most general aviation aircraft. It is assumed that all commercial air carriers will implement the additional avionics should an IPC VHF data link be initiated by the FAA. The implementation of a company communications data link (ACARS) is receiving considerable attention from most air carriers and may ultimately provide the service to all commercial air carriers. Not all military aircraft are expected to incorporate an IPC VHF data link as standard avionics. Indications are that the Military Airlift Command (MAC) fleet will include an IPC data link since MAC currently uses many of the same facilities, equipment configurations, and flight paths as the commercial aviation population. An assumption that 50 percent (10 of the 20) military aircraft in the LAX Basin are MAC aircraft yields a conservative estimate of the maximum loading of the IPC data link. The remaining 10 military aircraft are assumed to be in local operations in the vicinity of area military bases (such as Point Mugu, Edwards AFB, NAS Los Alamitos, etc.). The general aviation population

is composed of privately owned pleasure aircraft, as well as an assortment of high-performance aircraft such as large pure-jet cargo aircraft, air-taxis, and executive/corporate aircraft. Approximately 10 percent (72 aircraft) of the latter categories are expected to represent possible users of the ACARS data link network.* Projections of avionics capabilities (Reference 10) of general aviation outside the TCA and below 10,000 feet MSL indicate that at least 15 percent of these aircraft can be expected to be retrofitted for IPC. This 15 percent is representative of the above-mentioned high-performance general aviation and an additional 5 percent of limited-performance privately owned aircraft.

Los Angeles International Airport is classified as a Group I TCA, a rating requiring that all aircraft entering the TCA contain a transponder with Mode C capability.

Table 4-3 summarizes these facts and assumptions. It also indicates that the number of aircraft equipped for data link communications need not equal the total number of aircraft in the area. An example is that, of the

Table 4-3. ASSUMED AVIONICS CAPABILITY OF AIRCRAFT IN THE LOS ANGELES BASIN MODEL

Aviation Class and Status	Avionics Capability (Number of Aircraft)			
	IPC		ACARS	
	Equipped	Not Equipped	Equipped	Not Equipped
Commercial				
TCA	12	-	12	-
En Route	17	-	17	-
Mixed	4	-	4	-
General				
TCA	241	-	-	241
En Route	8	-	8	-
Mixed	50	273	-	323
VFR Highway	27	154	-	181
Military				
TCA	7	-	-	7
En Route	3	4	-	7
Mixed	-	6	-	6
Total	369	437	41*	765

*An additional 64 high-performance general aviation aircraft are expected eventually to be equipped for ACARS communication.

*The assumption of high-performance general aviation aircraft equipping for ACARS is based on the fact that a large percentage of these aircraft are currently users of the ARINC VHF radio network.

peak count of 806 aircraft within the total Los Angeles Basin at any instant, at least 45 percent will be expected to have IPC equipment in 1982. The sensitivity of the system concepts to the number of users was evaluated by exercising the analytical model for the 45 percent, 65 percent, and 100 percent IPC-equipped cases.

4.2 MESSAGE-ARRIVAL RATE

This section presents estimates of message arrivals per aircraft as a function of the airspace or service with which an aircraft is associated. Both IPC and ACARS message-arrival rates are incorporated into the communications capacity model described in Section 4.3. The generated IPC message-arrival rates will be applied to a varying aircraft population during the analyses of all the proposed system concepts and implementation options described in Chapter Two. The number of potential messages is related to the total number of aircraft, while the number of actual messages will be a smaller percentage depending on the extent to which the aircraft population is IPC-equipped. The ACARS message-arrival rate developed will be used on a selected population in the analysis of the IPC/ACARS proposed system concept and Implementation Concepts 1 and 2 of Table 2-1.

4.2.1 IPC Message-Arrival Rates

IPC commands will eventually be generated according to separation-assurance algorithms that are still undergoing development. These algorithms will reside in the ground IPC computer facilities and will consist of a series of software programs to calculate probable collision situations on the basis of the received surveillance data and certain constraints. Constraints such as warning range, maximum allowed accelerations, and minimum warning times for situations involving various aircraft types are still being investigated to yield a set of avoidance maneuvers and logic that is functionally capable for a maximum of situations.

Reference 11 postulates a simple version of the IPC algorithms and associated parameters for use in channel analysis. The IPC command in this simplified version of the algorithm is issued when two aircraft are predicted to come within 2000 feet horizontal or 500 feet vertical miss distances, and it is issued with a warning time of 30 seconds prior to collision. The algorithm calculates separation violations on the basis of instantaneous surveillance data, accounting for surveillance errors in speed, heading, position, and altitude, and ignores possible preplanned maneuvers by the aircraft within the warning time.

Figure 4-3 (reproduced from Reference 11) indicates the number of IPC command messages per aircraft per minute as a function of the amount of traffic in the area. This figure was developed by computing the expected conflict rate and assuming that each conflict requires two commands per aircraft for resolution. The conflict rate was derived by use of the horizontal/vertical miss distances and warning time stated in the simplified IPC algorithm.

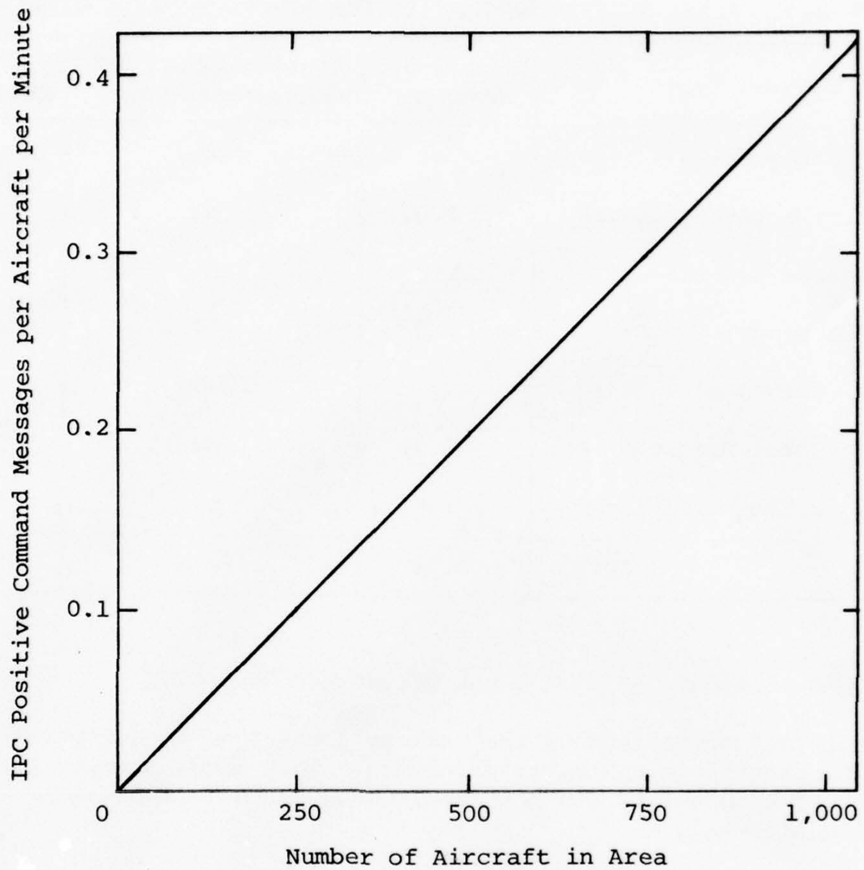


Figure 4-3. IPC MESSAGE-ARRIVAL RATES
(Reproduced from Reference 11)

4.2.2 ACARS Message-Arrival Rates

Message-arrival rates have not been generated specifically for expected ACARS traffic. Analysis of quarterly ARINC network air-ground contacts indicates that the approximate message rate derived from Table 4-4 can be justified. This table estimates the expected ACARS message types and text lengths of probable traffic during a one-hour flight. Table 4-4 yields an average message-text length of 89 characters and a mean message-arrival rate of 0.19 message per aircraft per minute.

Table 4-4. ACARS MESSAGE GENERATION PER AIRCRAFT IN ONE-HOUR FLIGHT			
Message Type	Number of Messages	Average Number of Characters (Text)	Total Characters
Position Reports	3.0	35	105
Departure/Arrival Reports	2.0	40	80
Maintenance Reports	2.0	15	30
Seat Occupancy	1.0	400	400
Special Services	0.1	1000	100
Airline/Hotel Reservations	2.0	90	180
Passenger Communications	1.0	90	90
Total	11.1	-	985

4.3 COMMUNICATIONS-CAPACITY MODEL OF THE VHF DATA LINK

To permit comparison of the various scenarios, an analytical model of data link channel capacity was developed. This model permits the priority ordering of both uplink and downlink messages and is applicable to all scenarios proposed.

Parameters of the model are the equipment characteristics and the bit rates discussed in Sections 3.4 and 3.5, respectively; the message lengths developed in Section 3.3; and the mean message-arrival rates developed in Section 4.2. The parameter sets used in the mathematical model exhibit the influence of equipment delay and bit rate on channel capacity and total channel delay times. The variable throughout the equations of the model is the total number of aircraft in the area. Consideration has been given to the data of Table 4-3 and the fact that the aircraft equipped for data link communications need not equal the total aircraft in the area. The model incorporates factors that compute the IPC conflict rate associated with the aircraft total but calculates the resulting transmission load on the basis of factors related to Table 4-3, the equipped aircraft, and the probability that one or both aircraft in a conflict situation will be IPC-equipped. ACARS traffic is a function of commercial air carrier and high-performance general aviation aircraft in the area. The quantity of aircraft generating ACARS communications traffic is bounded by minimum and maximum percentages of aircraft being equipped for ACARS service. These percentages are assumed to be constant as N (total number of aircraft) varies. Through a series of nonlinear equations derived from queuing theory techniques (simulating priority-ordered systems), the total channel utilization and fractional utilization attributed to each message type is calculated. Also calculated

are the means of service time, waiting time, and number of messages waiting for each message type, together with the standard deviation of waiting time per message type.

The mean waiting time and the standard deviation of waiting time are then used in a probability calculation. The normal distribution is used as an upper bound in calculating the time necessary to ensure with .99 probability that generated IPC messages have been delivered to the avionics. This time duration is called IPC uplink channel delay and, with the total channel utilization results, is plotted for varying numbers of aircraft for each parameter set and communications concept to illustrate the major indicators of channel responsiveness and availability.

Appendix B of this report contains the development and identification of the parameters and variables, the equations, and the computer listing of the model. It should be noted that the model does not take into account the retransmission of IPC messages necessitated by the occurrence of bit errors in the initial transmission. However, the impact of such transmissions on the operation of the VHF data links is predicted to be negligible. Calculations indicate that the probabilities of initially receiving an IPC message correctly in a dedicated VHF duplex system are 0.9969 and 0.9957, respectively, for 2400-bps and 4800-bps transmission rates with assumed bit error rates of 5.5×10^{-5} and 7.7×10^{-5}. The use of repetitive transmissions (as proposed in Section 2.2.2) in the dedicated VHF one-way data link concept results in a probability of 0.999 that at least one IPC message of a transmitted "string" of three will be received correctly for both 2400-bps and 4800-bps rates. For a transmission rate of 2400-bps, initial IPC messages are received correctly over the IPC/ACARS data link with a probability of 0.9899. Therefore, the percentage of retransmissions will be very small, and the error-detection features will prevent the display of erroneous commands.

4.4 DESIRED COMMUNICATIONS CHARACTERISTICS

The desired communications characteristics of an IPC VHF data link are now formulated to provide the guidelines needed to determine the admissible equipment parameters and system requirements for each proposed data link concept and implementation option. The characteristics that should be examined to determine the practicability of a digital communications system are the initial performance at implementation time, growth potential, and stability of operation of the link. These characteristics can be qualitatively analyzed by examining the output of the communications capacity model.

The computer model is exercised for increments of 50 aircraft in the area. Varying the total number of aircraft in the area from 50 through 900 provides the data for correlating the hourly fluctuations of traffic density in an area to the probable operating boundaries of channel utilization and channel delay for the IPC system. The upper limit of 900 aircraft used in the communications model is related to the 1982 peak Los Angeles Basin traffic level and includes an additional 100 aircraft to

account for some of the impact due to overlapping IPC coverage areas. The Los Angeles traffic model has been assessed as representing the worst-case peak traffic environment envisioned for terminal areas for the 1980s. This analysis, therefore, assumed that nationwide implementation of an IPC data link would not be subjected to near-term peak terminal-area traffic densities greater than those considered by the study.

Initial performance will be judged by the ability of a proposed system to handle the expected level of IPC-equipped aircraft of the early 1980s. This capacity is measured by the results of the communications model when exercised within the constraint of 45 percent of the aircraft population being equipped with IPC.

Growth potential for the dedicated-IPC-link concepts will be measured through conclusions drawn from the 65 percent and 100 percent IPC-equipped analyses; for the IPC/ACARS concepts, the measurement will be based on the probable operating region with an upper bound of IPC and ACARS use. These figures do not increase the aircraft density in an area but are representative of an increase in the number of aircraft retrofitting for participation in an implemented IPC system. Stability of operation of a concept is qualitatively defined as the ability to accept small numbers of additional aircraft into the system without drastically affecting channel utilization or channel delay time. Ranges of stability of operation for the concepts are therefore dependent on the behavior of both families of graphs (presented in Section 4.5.1). Since both families of graphs exhibit an exponential behavior, the optimal operating regions are those in which the extremely rapid growth typical of exponentials is not present.

In any event, total channel utilization and delay times should not exceed 70 percent and 2 seconds, respectively. The channel utilization figure is a conservative estimate of the system operation attainable with current avionic and ground equipment reliability and duty-cycle factors. The maximum channel delay time of 2 seconds is equivalent to expected mean delay times in providing similar separation-assurance information to aircraft by different data link concepts.

These constraints can be applied to the communications system concepts based on one nationwide uplink frequency or based on altitude banding of the IPC traffic. The four-frequency altitude-banding concept discussed in Chapter Two was advanced to reduce traffic demand on a proposed channel-management technique. In this concept, the effective maximum number of aircraft generating IPC commands and being handled by a single frequency is smaller than the total number of aircraft in the area. Therefore, the channel capacity of each of the altitude bands must be sufficient only to sustain the maximum number of aircraft expected in the most heavily traveled altitude band. The number of flight levels to be handled by each channel is not specified in this report. The method used to approximate the reduction in channel utilization and delay time due to altitude banding is outlined in Appendix C.

4.5 APPLICATION OF ANALYTICAL MODEL

The mathematical model computes the channel capacities for each implementation scheme and system concept by exercising the data link characteristics, message-arrival rates, and equipment data link capabilities. The parameter sets used in each exercise of the channel-capacity model are given in Table 4-5. These three sets of equipment characteristics are representative of equipment currently in use by the ATC system and the aviation communities and are derived from the discussions of Section 3.3 and Section 3.4. The varying of results caused by the use of these parameter sets will provide insight into the sensitivity of channel capacity to data link equipment characteristics. Factors relating the avionic IPC data link implementation to the total aviation community of the Los Angeles Basin were developed by the model discussed in Appendix B from the data of Table 4-3. The factors are based on TOS capability for 45 percent, 65 percent, and 100 percent of the aircraft in an area. The inputs of each concept are the types, lengths, and priority ordering of each message on the link.

Table 4-5. PARAMETER-SET DATA

Parameter Set	Bit Rate (bps)	Equipment Delay Times (Seconds)* as Seen by:		Performance Comments
		Avionics	Ground	
A	2400	0.15	0.1	Can be obtained with all of today's equipment.
B	4800	0.15	0.1	Obtainable with most of today's equipment.
C	4800	0.08	0.05	Typical for CA avionics and FAA ground equipment

*Correlation of these data with those of Sections 3.3 and 3.4 is presented in Appendix B.

Each of the following subsections is directed toward a particular implementation scheme or system concept and examines the implications of two families of graphs. The first family of graphs depict total channel utilization versus total number of aircraft in the area. The second family of graphs consists of plots of the IPC uplink channel delay time versus total number of aircraft in the area -- given that the probability of the generated IPC command being transmitted to and processed by the avionics within this time must equal 0.99. The six graphs presented for each concept (three-channel utilization, and three-channel delay) are paired according to the parameter set that was used in developing the computer model results.

The results of the analytical model indicate that for each concept proposed, there exists at least one of the parameter sets of Table 4-5 for which the channel-management scheme and system configuration of the concept could successfully be implemented to handle the expected initial IPC communications of the 1982 traffic model. The economic analyses (Chapter Five) provide the unit avionics costs, which are dependent on the avionic equipment performance parameters necessary to implement each IPC concept.

The derivation and source of the data used for each scenario are explained in Appendix B.

4.5.1 Case 1: Dedicated IPC VHF Data Link Handling All Aviation Classes

4.5.1.1 One-Way Link

Figures 4-4 through 4-6 were developed under the constraints of an IPC dedicated one-way data link. To improve the probability that IPC commands received by the aircraft will be properly decoded, each transmission is composed of three consecutive IPC message formats, including the IPC text (command), aircraft address, block check sequence (BCS), and remaining overhead bits of the message. Qualitative judgments of the model's output for the dedicated one-way IPC data link can be drawn for both the concept of a single nationwide channel and the concept of a set of four altitude-banded nationwide channels.

A single nationwide frequency should be implemented only on channels that exhibit the capability for "vertical growth" -- the ability of the channel (i.e., the system) to provide sufficient IPC service to a given area as the percentage of aircraft seeking the service increase. Figure 4-4 indicates that the use of existing equipment characteristics and a bit rate of 2400 bps (parameter Set A of Table 4-5) can initially handle the expected peak load of 360 IPC-equipped aircraft out of the 800 in the Los Angeles Basin. The growth capability and overlap surveillance capability, however, are limited because of severe problems in stability of operation. These problems are typified by the increases in channel utilization (for N=800, $\rho_{45\%} = 0.47$, $\rho_{65\%} = 0.66$, and $\rho_{100\%} \geq 1$) and, more important, the projection of large channel delay times greater than 10 seconds for the generation, transmission, and receipt of an IPC command in an 800-aircraft environment with 100 percent IPC-equipped.

Figure 4-5, developed from parameter set B, indicates the sensitivity of the data link to bit rate alone. Figure 4-5(a) indicates improvement in channel-utilization factors over analogous points of Figure 4-4(a) (i.e., at 800 aircraft: $\rho_{100\%} = 0.80$ for parameter Set B, as compared with $\rho_{100\%} \geq 1$ for parameter Set A). Figure 4-5(b) identifies the N=800 aircraft level of both the 65 percent and 100 percent IPC-equipped curves as areas of unstable operating regions for channel delay times, limiting the time responsiveness and system effectiveness at these levels.

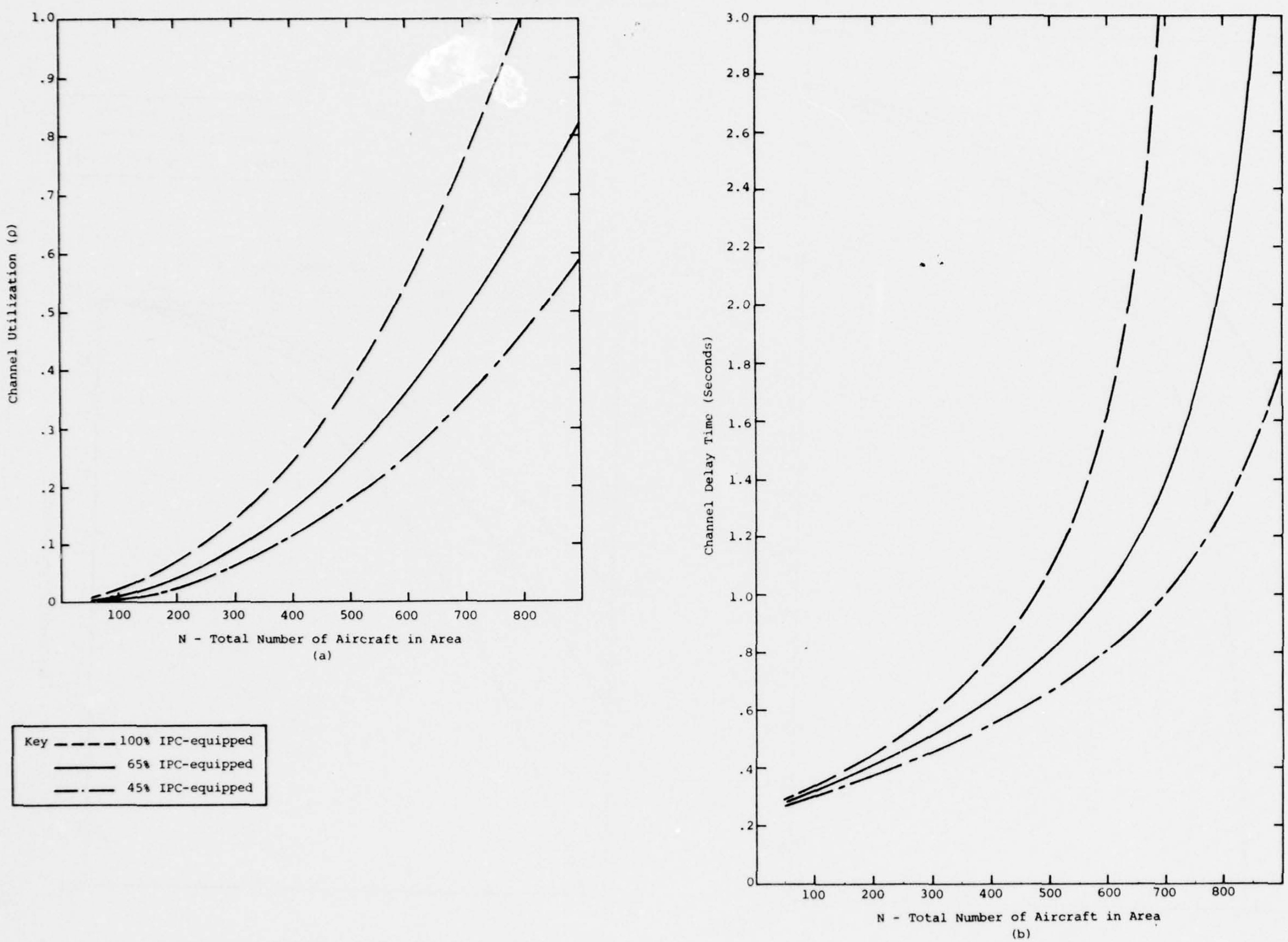


Figure 4-4. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC ONE-WAY DATA LINK (PARAMETER SET A)

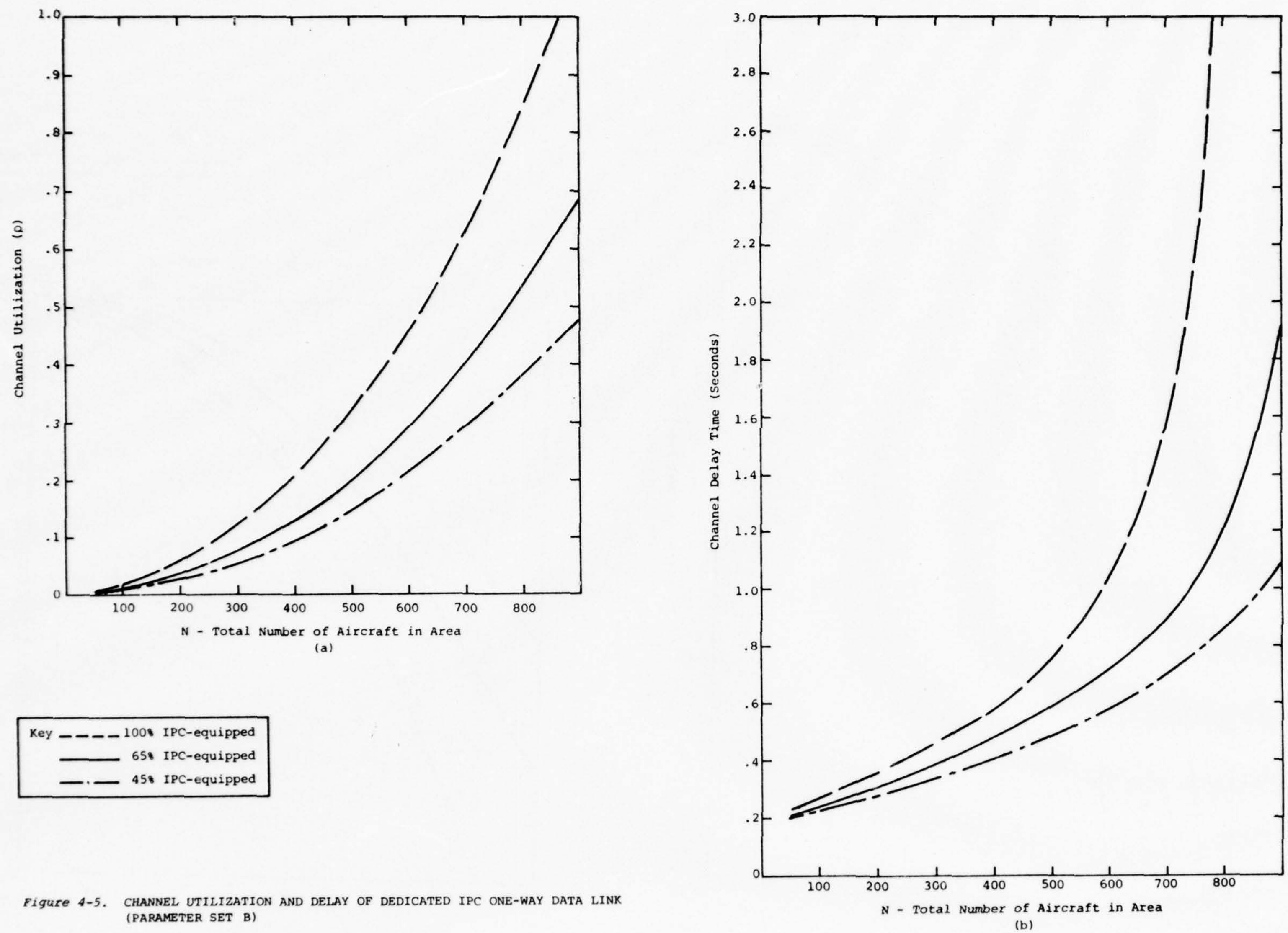
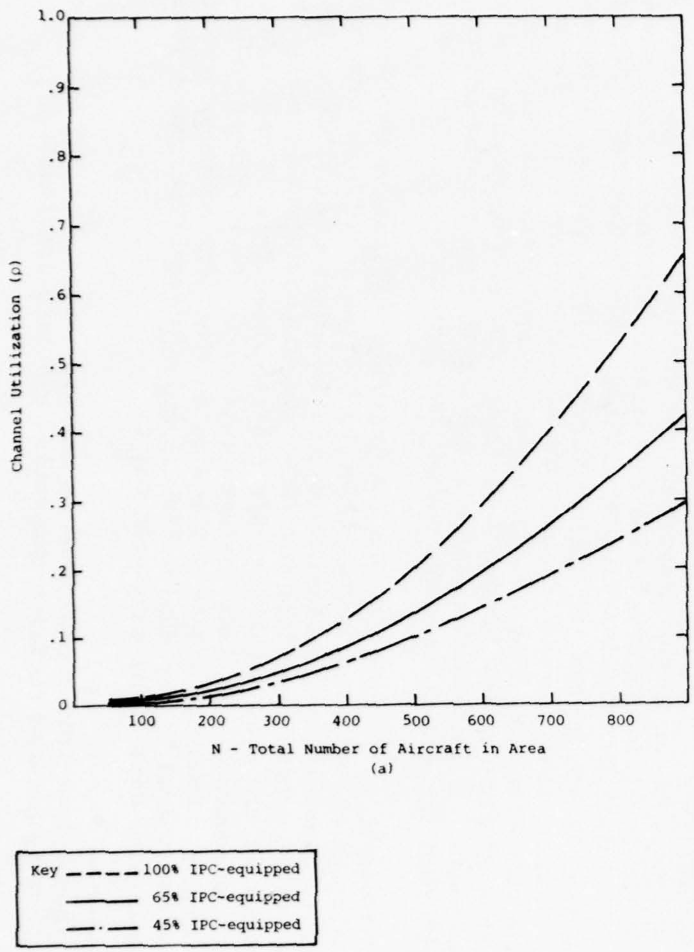


Figure 4-5. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC ONE-WAY DATA LINK (PARAMETER SET B)



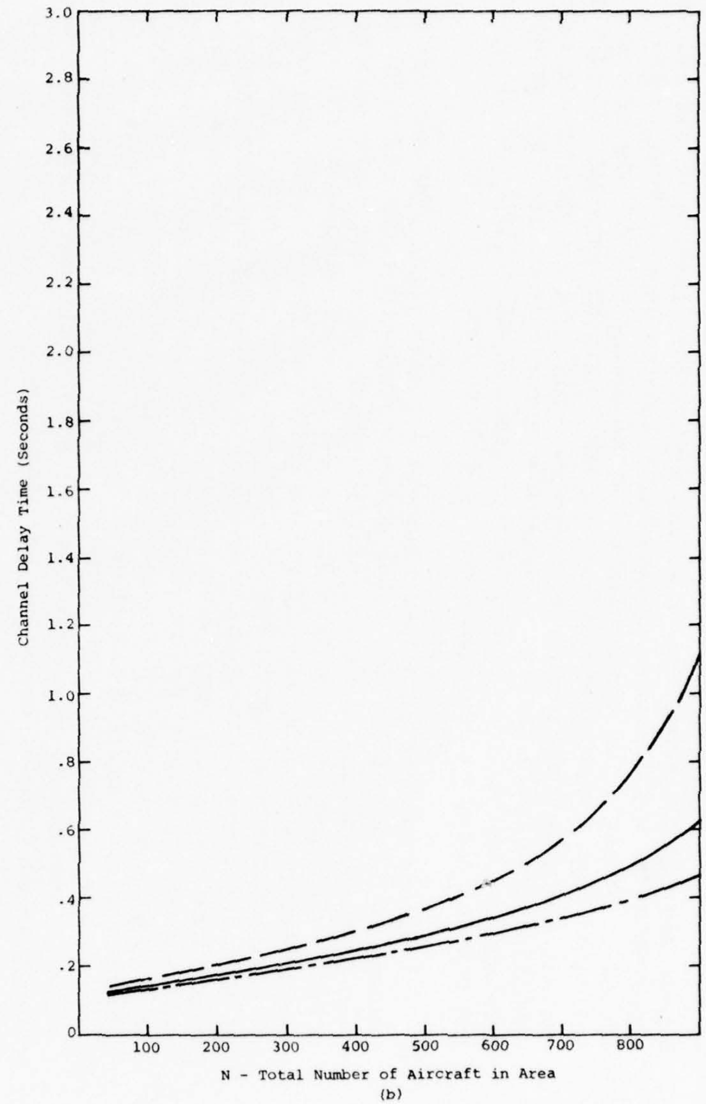


Figure 4-6. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC ONE-WAY DATA LINK (PARAMETER SET C)

The results of using parameter Set C in the computer model are shown in Figure 4-6. The graphs indicate, not only for this channel-management scheme but for all scenarios, that the key factors leading to significant improvement in utilization and time delay are the shorter avionic and ground equipment delay times typified by parameter Set C. Figure 4-6 indicates that a dedicated one-way IPC VHF data link composed of modified current FAA ground equipment and avionics equivalent to current air carrier specifications could sustain at least 800 aircraft that are 100 percent IPC-equipped and exhibit stable, acceptable channel utilization ($\rho_{100\%} = 0.5$) and channel delay times (approximately 0.78 seconds).

Altitude banding with four frequencies, each capable of sustaining 30 percent to 75 percent of the total communications, has the effect of more than doubling the maximum total traffic density at which system saturation occurs*. Calculations made from Figure 4-5 indicate probable performance characteristics of channel utilization and delay times (under the concept of altitude banding) within the desired limits of Section 4.4. The impact of this improvement can be appreciated by considering the fact that equipment currently used by most general aviation aircraft (equipment that is well within the specifications of commercial air carriers) can be modified to support a data link of sufficient capacity and stability to sustain the expected message traffic well beyond that predicted by the 1982 Los Angeles Basin traffic model and this analysis. Therefore, it is possible to use either a one-channel parameter Set C or a multi-channel parameter Set B design in configuring a one-way IPC data link.

4.5.1.2 Duplex Link

Figures 4-7 through 4-9 were developed by considering the two-way (duplex) configuration of the dedicated IPC data link concept. Because there is some form of acknowledgment by the aircraft of receipt of an IPC command, the condition of repetitive transmissions present in the one-way case was eliminated. The longest IPC message reply discussed in Section 3.2 was the same length as the IPC uplink command. This symmetry of message traffic implies that the channel utilization and channel delay time on the downlink can be no more than on the uplink for any given traffic density. The graphs of Figures 4-7 through 4-9, therefore, represent only the uplink message loads. A qualitative analysis similar to that for the one-way link was performed for a dedicated VHF duplex IPC data link.

The curves of Figures 4-7 and 4-8 indicated sufficient improvement over the analogous one-way link curves (Figures 4-4 and 4-5) to be considered for initial implementation as a nationwide single-uplink-channel data link. To ensure stable growth potential for IPC-equipped populations greater than 65 percent of the area total aircraft traffic, some form of modification to channel management, data link characteristics, or IPC warning time would be necessary. However, Figure 4-9 indicates that none of these modifications need be considered if the duplex link is constructed of equipment possessing the capability defined by parameter Set C.

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*Less than a four-fold improvement is realized because of the nonlinear relationship between conflict generation and aircraft density.

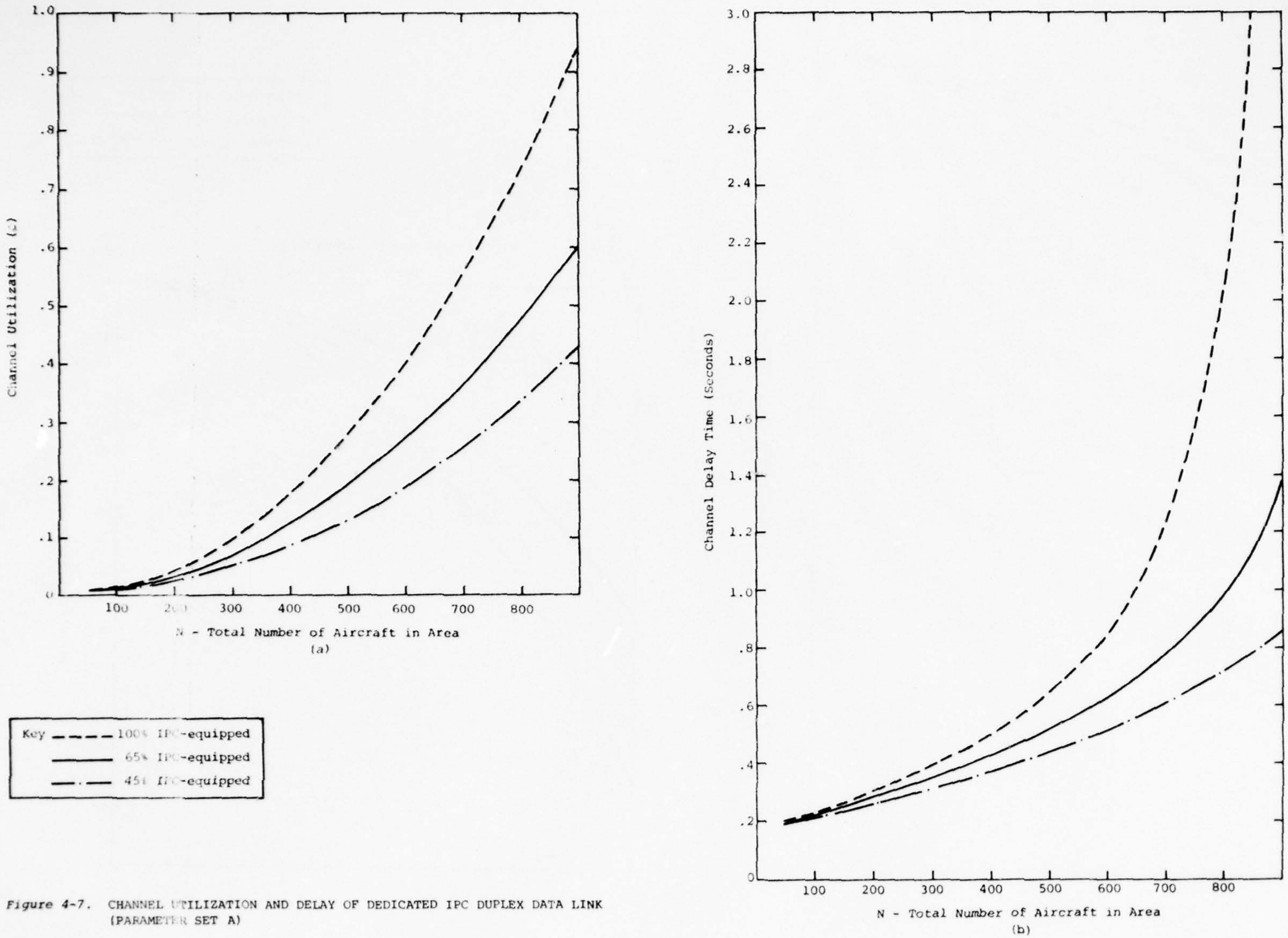

Figure 4-7. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC DUPLEX DATA LINK (PARAMETER SET A)

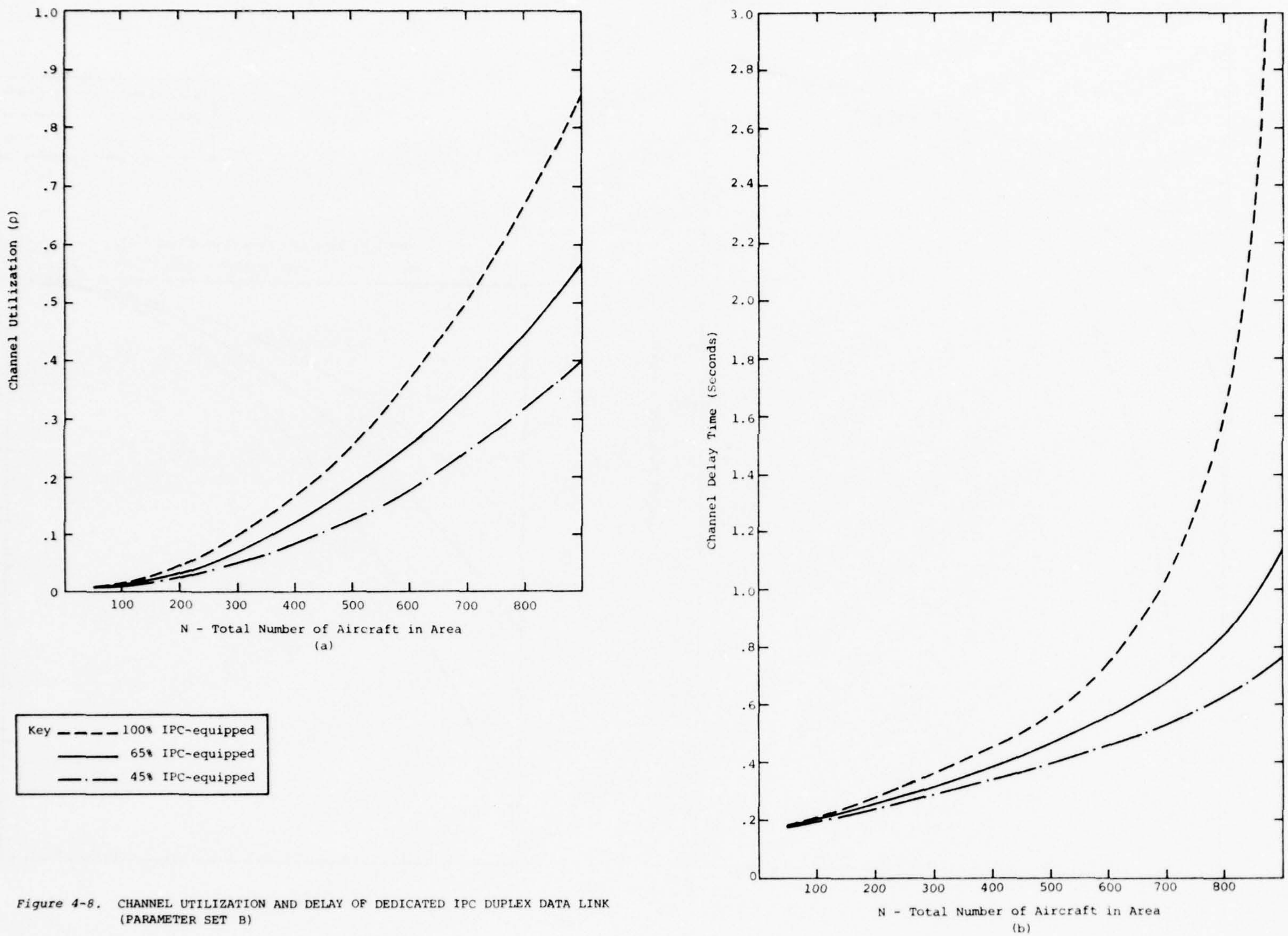

Figure 4-8. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC DUPLEX DATA LINK (PARAMETER SET B)

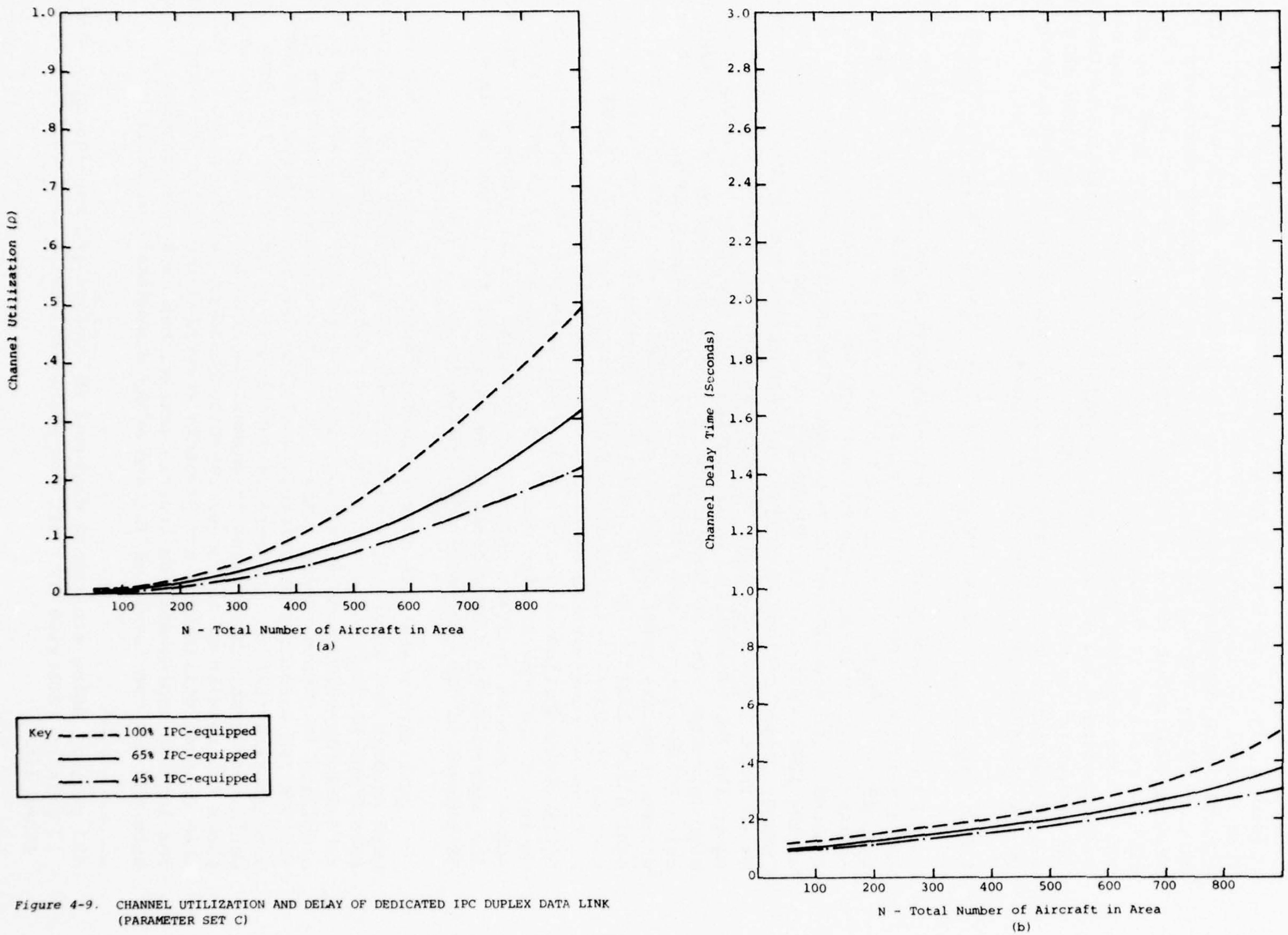

Figure 4-9. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC DUPLEX DATA LINK (PARAMETER SET C)

Altitude banding of the duplex option provides a solution to the channel-saturation problem indicated in Figures 4-7 and 4-8. With this technique, it is possible to avoid unacceptable channel delay times and high channel utilization factors and still provide IPC to potentially all aircraft with equipment currently in use (parameter Sets A and B). The data of Figure 4-7 can be used to show that a 25 percent improvement in channel utilization and a 45 percent improvement in channel delay time will be realized if operations are switched from a single frequency to a set of four altitude-banded frequencies (see Appendix C). As discussed in Subsection 4.5.1.1, long-term capability of a single uplink nationwide VHF frequency for use by an IPC duplex data link can be provided only through use of parameter Set C characteristics, whereas multi-channel altitude banding can be designed with parameter Set A characteristics.

4.5.2 Case 2: IPC/ACARS VHF Data Link Handling All Aviation Classes

Figures 4-10 through 4-12 were developed under the constraints of an IPC and company communications priority-ordered data link. The traffic assumed on the data link, in order of priority, consisted of uplink IPC commands, uplink ACARS technical acknowledgments, downlink replies to IPC commands, and downlink ACARS messages. The initial implementation of IPC on the ACARS data link is indicated by the 45 percent IPC-equipped curve. Company communications at initial implementation are expected to be generated by at least 5 percent of the aircraft in the area. As additional aircraft equip for IPC capability, it is assumed that the number of ACARS users will also increase. The estimated upper bounds of 13 percent of area traffic being ACARS-equipped and 100 percent being IPC-equipped* are used by the channel-capacity model as the maximum number of aircraft generating communications traffic for the data link. Therefore, the probable operating regions of channel utilization and delay times for an IPC/ACARS data link are bounded by these two curves. These levels of aircraft equipped for ACARS communications are consistent with Table 4-3, the population distribution of the 1982 traffic model. The message-arrival rates for IPC and ACARS communications are obtained from Figure 4-3 and Table 4-4, respectively. The channel-delay graphs continue to represent the uplink IPC delay time for 99 percent of the generated IPC traffic.

Qualitative analysis of Figures 4-10 and 4-11 indicates that currently used avionic and ground equipment for both 2400 bps and 4800 bps (parameter Sets A and B) are unacceptable because of extremely high channel utilization and unstable channel delay times. In these two cases, efforts to increase stability in channel delay times or to reduce channel utilization by adjusting the IPC warning-time criteria would involve such a large increment of warning time that the increase in unnecessary or erroneous IPC commands would offset any improvement in channel capability. Figure 4-12, which shows the results of the model exercise based on parameter Set C, indicates that channel utilization and probable channel delay times are acceptable for initial-implementation traffic levels, but cannot successfully accommodate the maximum levels of IPC and ACARS communications traffic.

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*87 percent using mini-ACARS designed to receive IPC message only, and 13 percent receiving both IPC and ACARS, all being transmitted over the ACARS link.

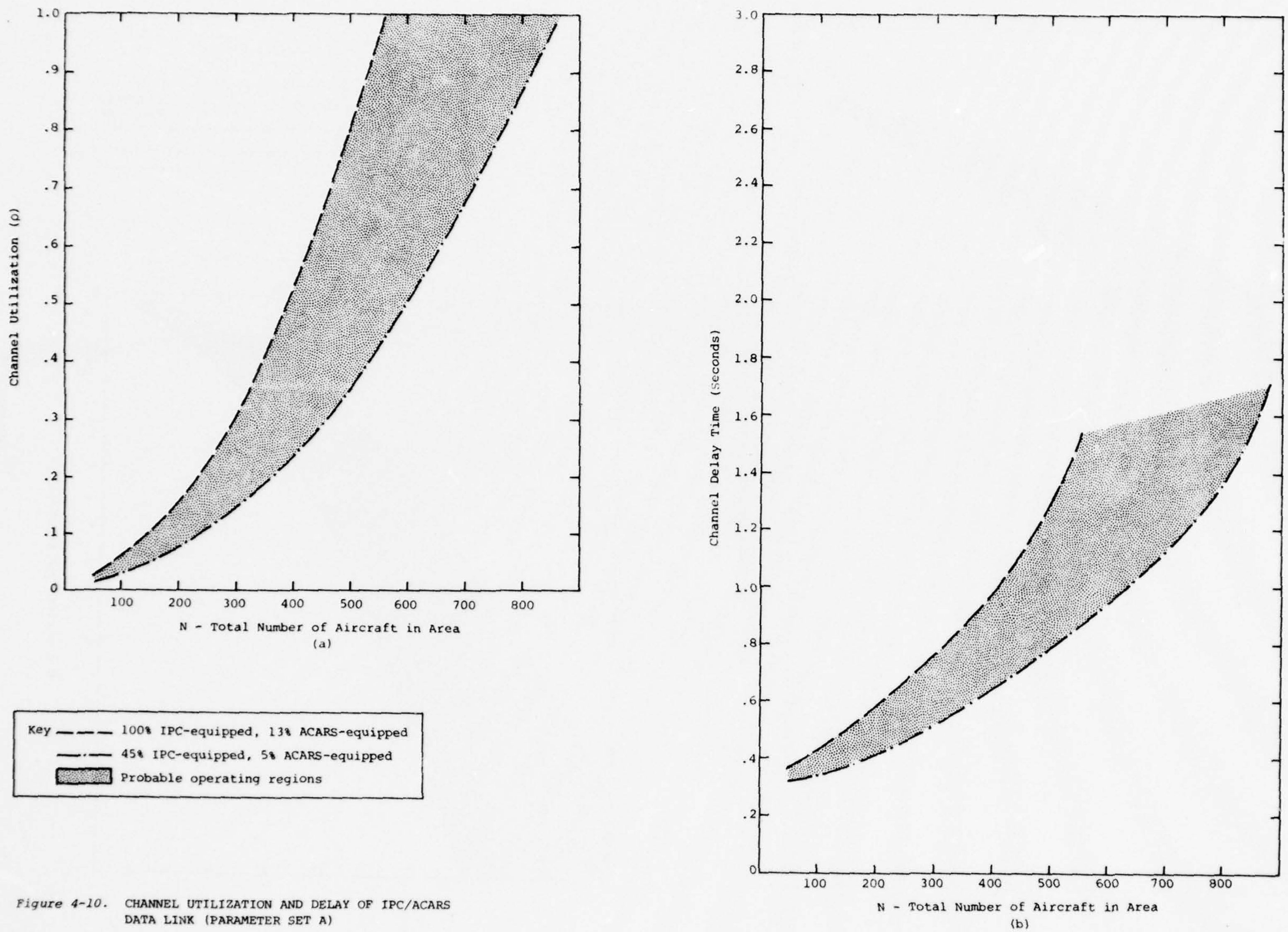

Figure 4-10. CHANNEL UTILIZATION AND DELAY OF IPC/ACARS DATA LINK (PARAMETER SET A)

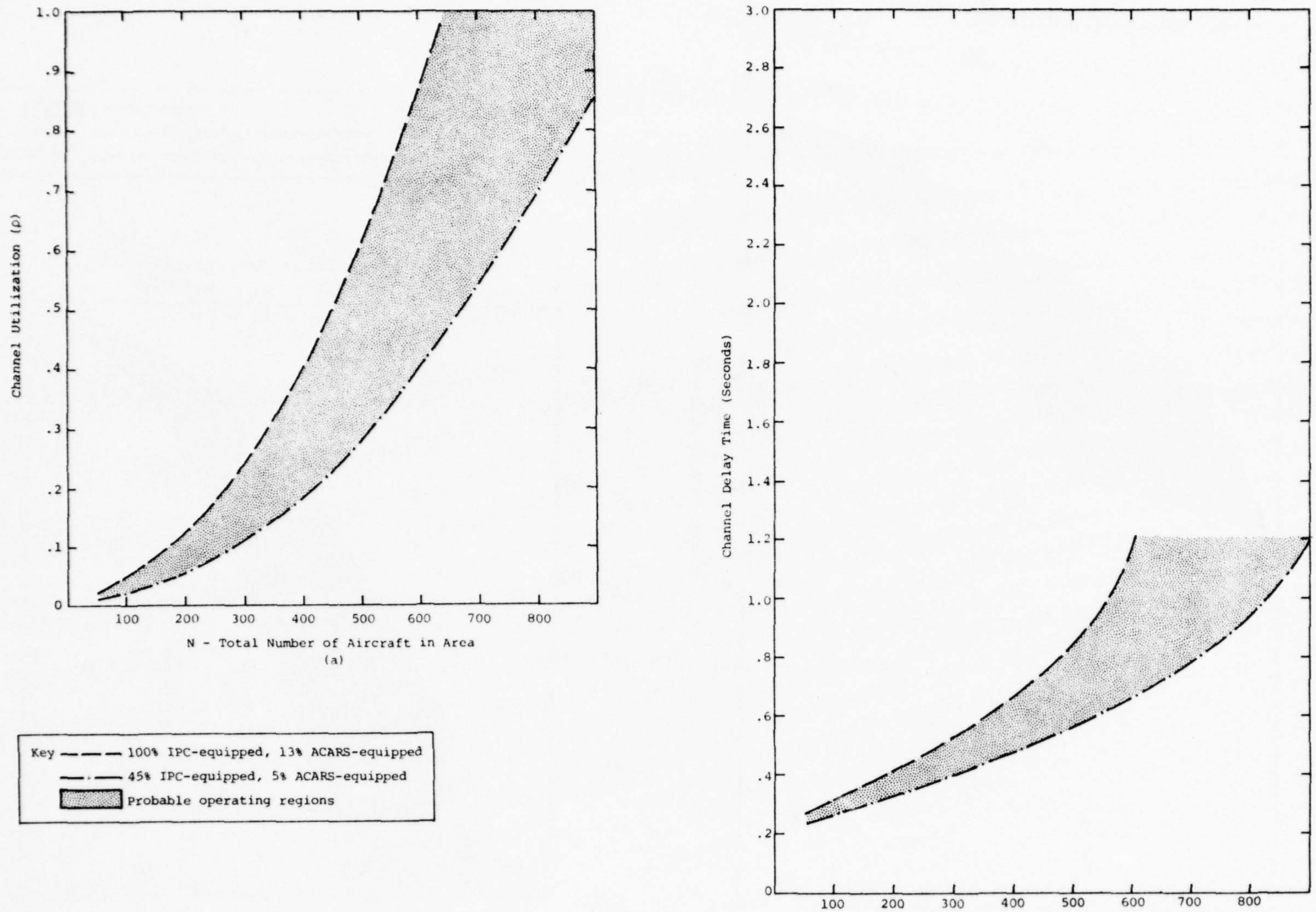

Figure 4-11. CHANNEL UTILIZATION AND DELAY OF IPC/ACARS DATA LINK (PARAMETER SET B)

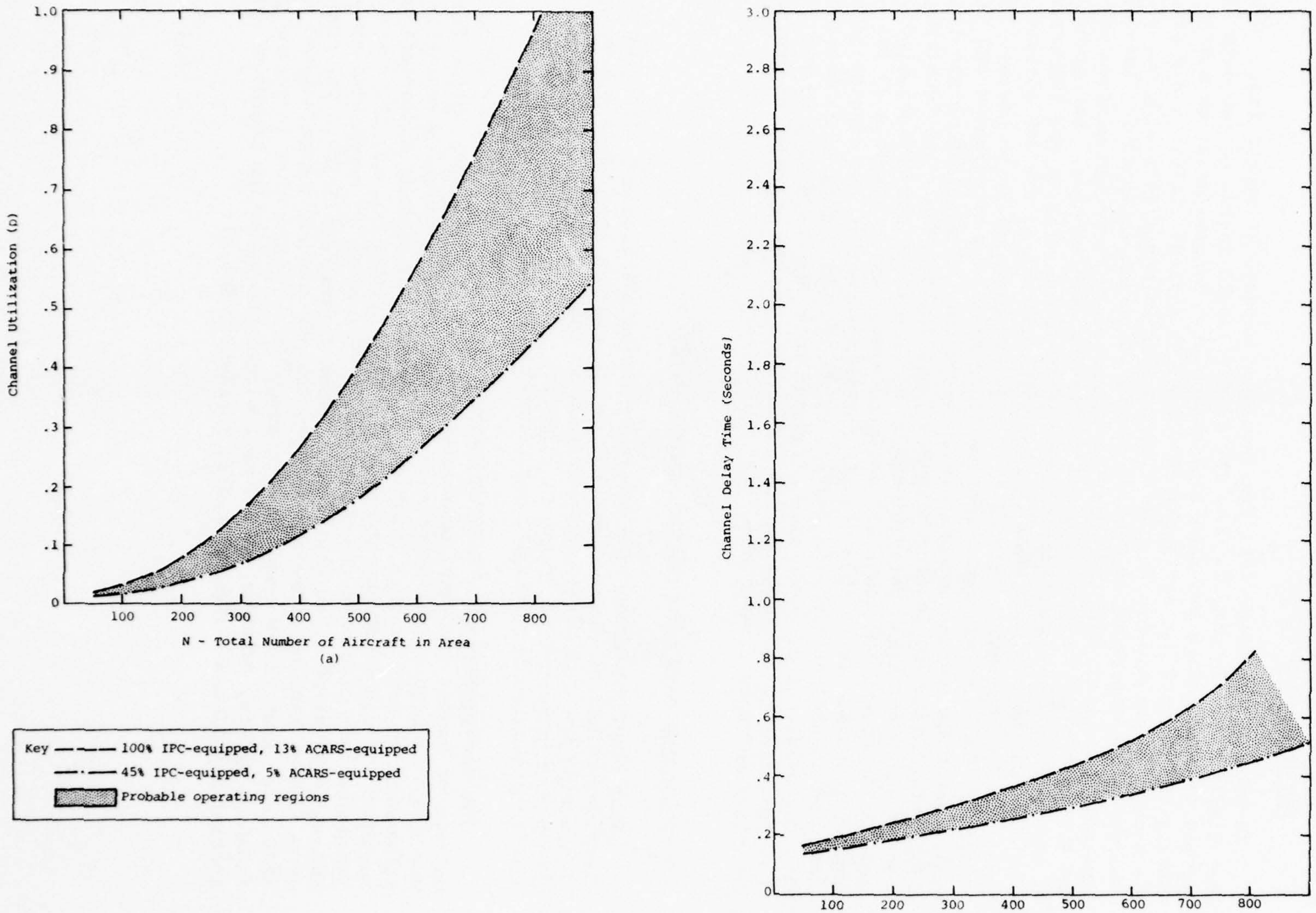

Figure 4-12. CHANNEL UTILIZATION AND DELAY OF IPC/ACARS DATA LINK (PARAMETER SET C)

4.5.3 Case 3: IPC/ACARS Link for ACARS Users and IPC Dedicated Data Link for Non-ACARS Users

In Case 3, the ACARS data link would be exposed to substantially much less traffic than in Case 2. The IPC traffic would reside on two data link systems (and therefore two data link channels). General aviation users seeking IPC service but not equipped for ACARS message traffic would procure the necessary avionics to receive IPC commands in compliance with one of the configurations discussed in Section 4.4.1. Aircraft equipped for ACARS data link communications would be modified as necessary to permit maximum use of the ACARS avionics in receiving and processing IPC commands. The magnitude of the reduction in communications competing for service on the IPC/ACARS data link can be realized when it is considered that of the 360 aircraft receiving IPC commands in Figure 4-10 (for 800 aircraft at 45 percent IPC-equipped), 320 aircraft would receive IPC commands on a dedicated IPC data link under this system concept. This leaves only 40 aircraft on the IPC/ACARS data link communicating both ACARS and IPC traffic. The resulting channel utilization and delay times for 5 percent IPC and ACARS-equipped through 13 percent IPC and ACARS-equipped are shown in Figure 4-13 for parameter Set A. It is this significant improvement in the channel delay times and channel utilization factors of an IPC/ACARS data link, together with the existence of acceptable parameter sets for the dedicated IPC case, that justifies this implementation option as a viable approach to providing IPC via a VHF data link system.

4.6 RESULTING DATA LINK DESIGN REQUIREMENTS

This section presents the equipment characteristics and data link parameters determined as the minimum required to provide acceptable system operation during the near-term implementation of the IPC options analyzed by the channel-capacity model. These requirements are presented in Table 4-6 and briefly discussed for each IPC implementation option.

The development of a dedicated IPC data link configured for either one-way or duplex (two-way) operation on a single nationwide uplink frequency was found to require the support of equipment characteristics typically not attainable by most general aviation avionics. The minimal characteristics required for competent operation of the one-uplink-frequency IPC systems (parameter Set C) demand the use of avionics typical of commercial aviation and the equivalent of current FAA-equipped ground facilities. The concept of altitude banding, however, reduces the per-channel communications load to a level that can be handled adequately by equipment that is commonly found in general aviation and is well within the operating bounds of commercial aviation and FAA facilities (parameter Set A).

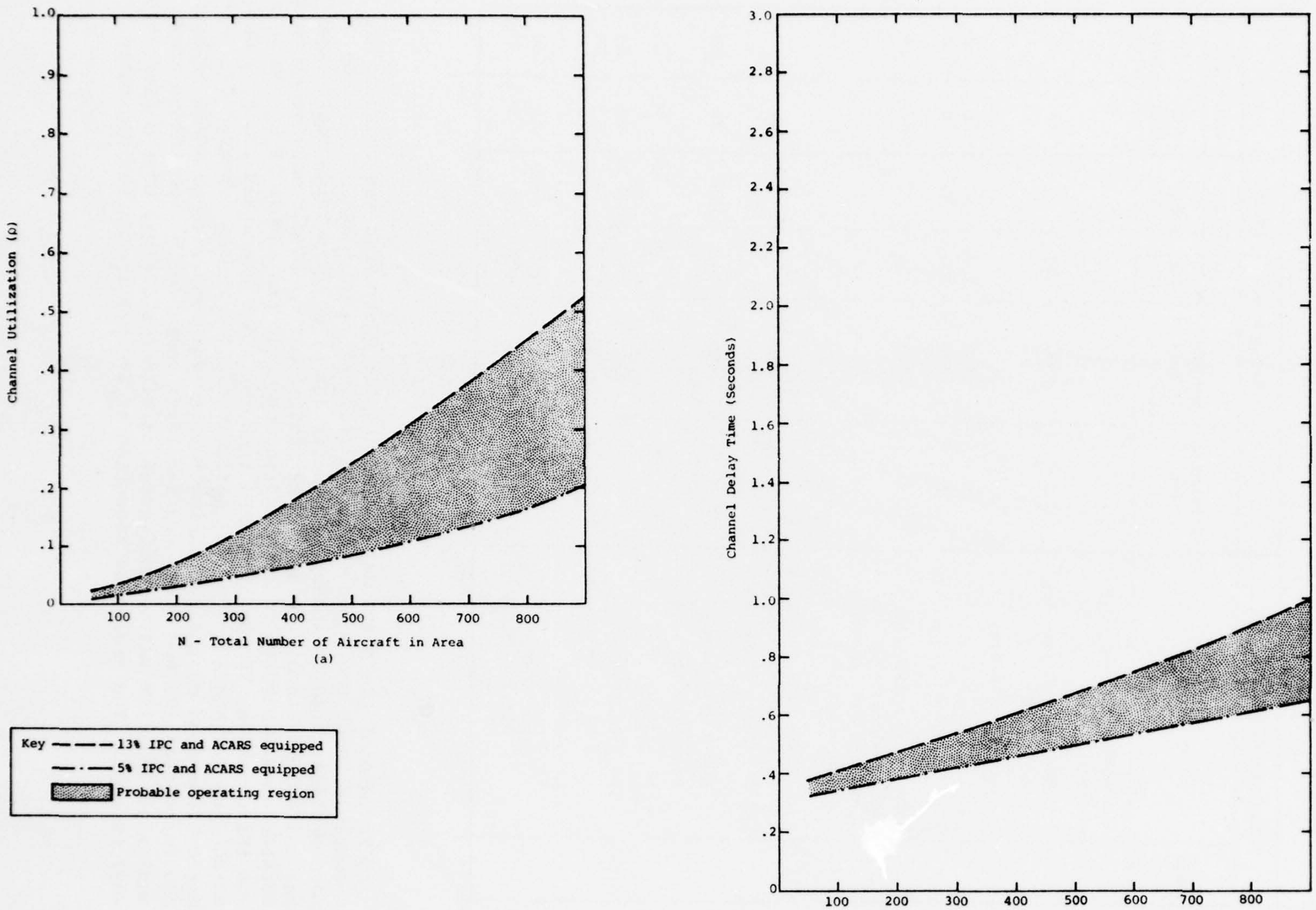

Figure 4-13. CHANNEL UTILIZATION AND DELAY OF IPC/ACARS DATA LINK FOR USE BY ACARS USERS ONLY (PARAMETER SET A)

Table 4-6. DATA LINK DESIGN REQUIREMENTS RESULTING FROM CHANNEL-CAPACITY ANALYSIS							
Implementation Option		Minimum Requirements					
				Avionics		Ground	
Case	Description	Parameter Set	Bit Rate (bps)	AGC (ms)	CRT (ms)	AGC (ms)	CRT (ms)
1	Dedicated IPC VHF Data Link						
	One Channel (one way or duplex)	C	4800	50	25	25	25
	Altitude banding						
	One Way	B	4800	100	50	50	50
	Duplex	A	2400	100	50	50	50
2	IPC Using ACARS Data Link (adequate initial capacity but limited growth potential)	C	4800	50	25	25	25
3	IPC/ACARS Link for ACARS Users and IPC Dedicated Link for Non-ACARS Users						
	ACARS Data Link	A	2400	100	50	50	50
	Dedicated IPC Link						
	One Way						
	One Channel	C	4800	50	25	25	25
	Altitude Banding	A	2400	100	50	50	50
	Duplex						
	One Channel	B	4800	100	50	50	50
	Altitude Banding	A	2400	100	50	50	50

The use of the ACARS data link for all IPC traffic was found to be impossible under the current planned 2400-bps rate of ACARS. The use of more sophisticated equipment (parameter Set C) would provide ample capability for initial levels of IPC and ACARS traffic but could not provide acceptable service when subjected to expected increases in the number of system users. The third option, IPC on the ACARS link for ACARS users and IPC on a dedicated link for non-ACARS users, sufficiently lowers the expected IPC communications load on the ACARS link for the 2400-bps rate of ACARS to handle the forecasted IPC and ACARS traffic loads competently. The associated dedicated IPC link can be configured as either a one-way or a duplex (two-way) concept. The analogous reduction of IPC traffic on the dedicated IPC

link permits the use of equipment characteristics and link parameters obtainable with most, if not all, of the avionics and ground equipment in use today (depending on which dedicated concept is used).

The remainder of the study is directed toward the development of avionics costs for each implementation option. The development of these costs is dependent on the avionics complexity involved in complying with the implementation concept and associated design requirements of Table 4-6.

CHAPTER FIVE

IPC AVIONICS DESIGNS

The ability of a VHF data link to provide IPC information to equipped aircraft has been established, as shown in Chapter Four. However, the hardware required to implement each of the concepts advocated is unavailable or only partially available in the avionics inventory. This chapter identifies the equipment configurations required by each proposed concept for both air carriers and general aviation, and details the designs of new circuitry necessary for the manufacture of the VHF IPC avionics. Modules or subassemblies considered conventional and used currently in similar avionics (e.g., RF front-ends, IF amplifiers) are also identified.

5.1 CONFIGURATION OF IPC AVIONICS

The avionics required for each option proposed in Chapters Two and Four differ sufficiently to require separate designs. Since the options are not expandable to accommodate increased traffic density, no attempt is made to design units that could be modified at a future date through the addition or substitution of modules.

The configurations of avionics required for evaluation in this study are grouped according to the following system concepts:

- System Concept 1 - IPC Using a Dedicated VHF Data Link
  - Single Channel, Uplink Only
  - Single Channel, Duplex
  - Multi-Channel (Altitude Banding), Uplink Only
  - Multi-Channel (Altitude Banding), Duplex
- System Concept 2 - IPC Using the ACARS Data Link

Each concept requires a VHF receiver, signal processor, display, and antenna. Options such as Concept 1 duplex operation and Concept 2 require the addition of modulators and VHF transmitters. The block diagrams shown in Figures 5-1 through 5-6 represent a typical single-system implementation of each concept in either commercial air carrier or general aviation aircraft. (The numbers in parentheses within the blocks indicate the subsections in which the avionics modules are discussed.)

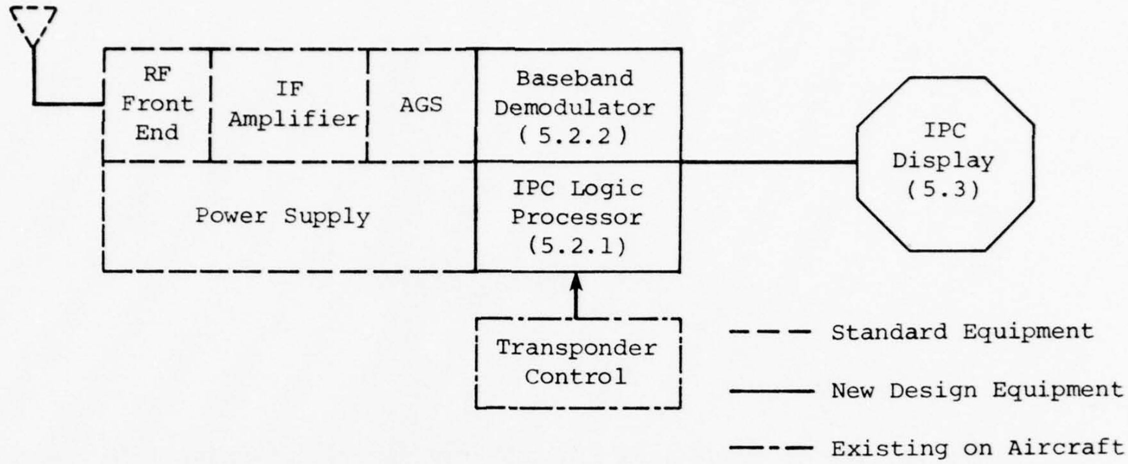

Figure 5-1. CONCEPT 1 - SINGLE CHANNEL, UPLINK ONLY

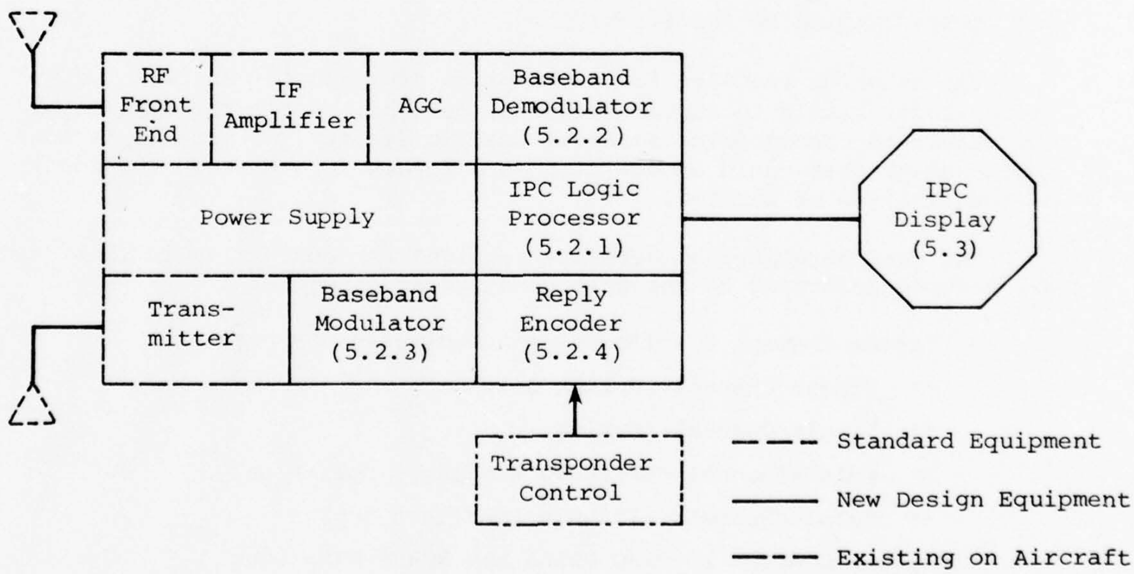

Figure 5-2. CONCEPT 1 - SINGLE CHANNEL, DUPLEX

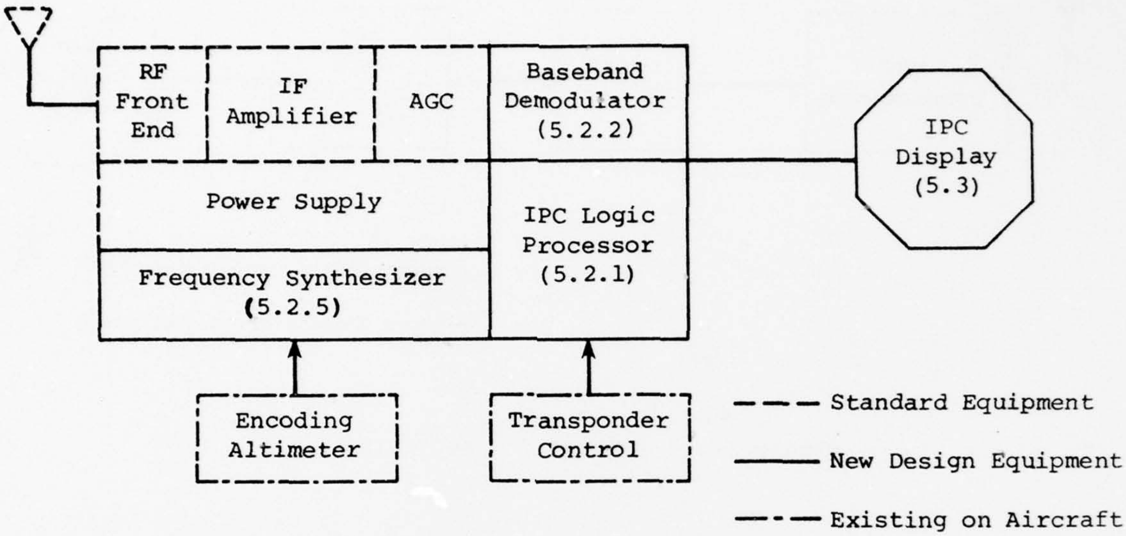

Figure 5-3. CONCEPT 1 - MULTI-CHANNEL, UPLINK ONLY

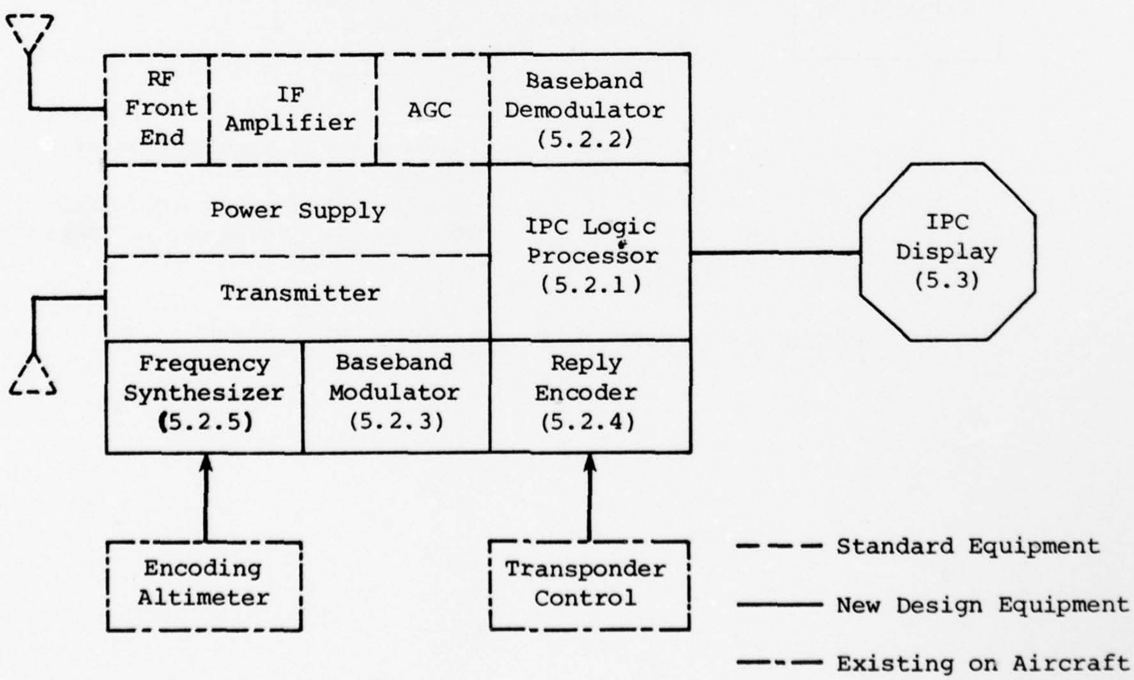

Figure 5-4. CONCEPT 1 - MULTI-CHANNEL, DUPLEX

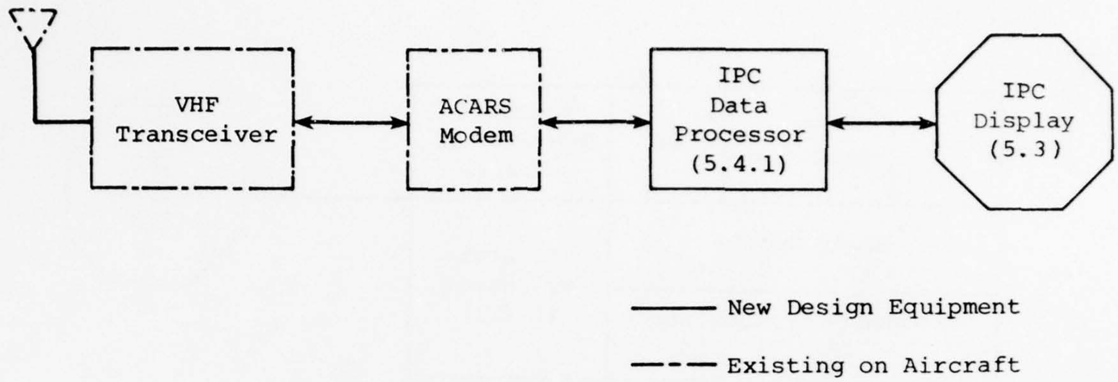

Figure 5-5. CONCEPT 2 - IPC USING ACARS

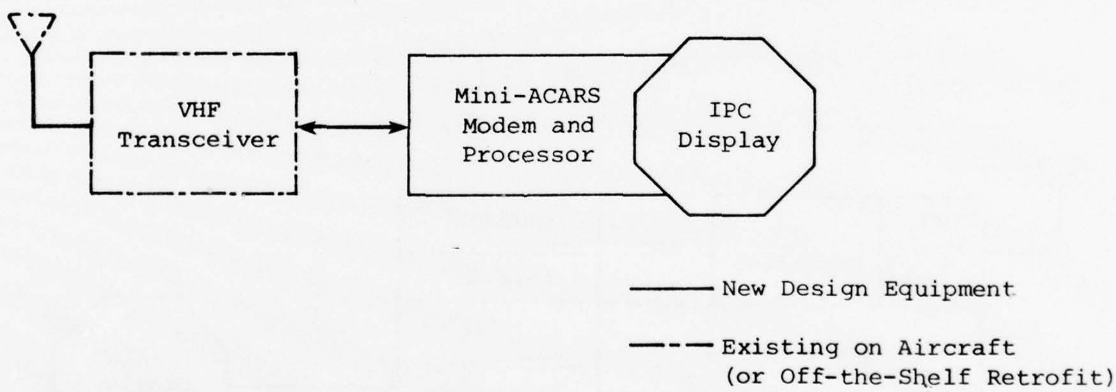

Figure 5-6. CONCEPT 2 - IPC USING MINI-ACARS

All avionics required by Concept 1 are considered new, requiring design and manufacturing but permitting maximum reuse of existing modules and design practices. Concept 2 avionics require the addition of a new IPC data processor and a new IPC display. The remainder of the avionics are considered to exist on air carrier aircraft in the period of implementation.

The equipment required by general aviation low-performance aircraft is functionally identical to the air carrier version and differs only in packaging, environmental requirements, and location in an aircraft. The general aviation practice of mounting the electronics and displays in the flight console has been adapted in the design of the general aviation VHF/IPC avionics. The equipment required by general aviation for Concept 2 includes a mini-modem capable of decoding an IPC message only, the logic processing and drivers, and an appropriate IPC display, all packaged in a single enclosure. The transceiver would be either the existing second VHF communications unit in the aircraft or a new standard VHF communications unit.

5.2 CONCEPT 1 - IPC USING A DEDICATED VHF DATA LINK

The introduction of IPC functions into aircraft operating in the national air space requires continuous monitoring of the ground-generated RF data link. Although VHF equipment now installed in aircraft is capable of receiving the IPC commands, it is designed to provide voice communications on any one of 720 VHF channels, requiring sophisticated synthesizers, front ends, squelch circuitry, and audio amplification. The resultant avionic equipment is a state-of-the-art transceiver incorporating functions not necessary for operation on a single frequency or a limited number (e.g., four) of frequencies. Implementation of the IPC under the VHF concept will require, in addition to a basic receiver/transmitter, logic processors, demodulators, modulators (for duplex operation), and display drivers. A practical and cost-effective approach is to develop and produce avionics dedicated to the IPC concept. The new avionics would reuse many of the modules currently installed in VHF transceivers but eliminate those modules not required for either single-frequency or data-link-only operation.

This section identifies the equipment that would require new design and development to complement the existing production modules in configuring a dedicated VHF radio for use in the IPC concept.

5.2.1 IPC Logic Processor

The critical requirements in providing collision avoidance commands to an aircraft are that the message be uniquely accepted by the addressed aircraft and that the command displayed to the pilot be the intended instruction of the IPC computer. This requirement is considered and adhered to in the logic design of the IPC decoding network. Figure 5-7 is a logic flow diagram of the activity and decision process of the logic design developed for all options of the dedicated VHF data link. Portions that apply to the duplex mode of this concept are evident.

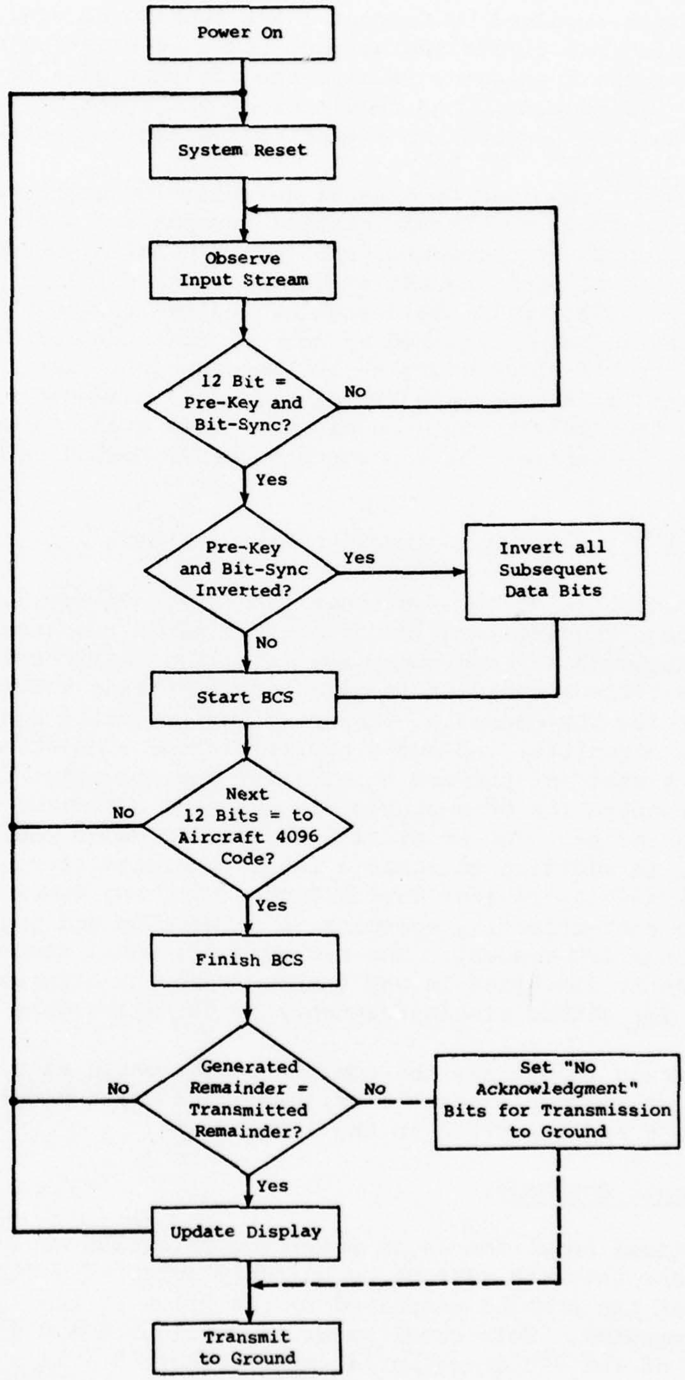

Figure 5-7. IPC USING DEDICATED VHF-LOGIC FLOW DIAGRAM

The system clears and resets when power is first applied to the avionics and subsequently resets upon command of the processing network. When data first appear from the demodulator, a check sequence of 12 bits of "Pre-Key" and "Bit-Sync" are tested to determine whether valid data can be expected. If these bits are not matched, the system will continue observation of the next input stream. A valid match permits continuation of data decoding and testing for inverted data. Data of proper polarity are then passed to a comparator circuit to check the message address. A block check sequence (BCS) is also initiated to confirm error-free reception of the message. If the designated address does not match the unique aircraft code, derived from the ATCRBS transponder control, the decoding is terminated and the system reset for the next reception. If, however, a valid address match is detected, the remainder of the message is decoded, the BCS is completed, and the generated remainder is tested against the transmitted remainder to confirm the reception of an error-free message. If no difference is detected, the IPC command is updated; a discrepancy results in rejection of the entire message and resetting of the system for the next message.

An additional feature shown on the logic flow diagram and incorporated into the duplex system configurations is the encoding of the entire message for retransmission to the ground IPC computers. The message, identical to the uplink transmission except for the acknowledgment/no-acknowledgment element, advises the IPC computers whether the aircraft has properly decoded the intended command.

The detailed logic design supporting the concept utilizes existing technology, with the majority of the components chosen from the discrete TTL logic family. A Read-Only-Memory (ROM) chip is used to control sequential functions and reduce total chip density. The design is adaptable to large-scale integration (LSI); however, the decision for custom design is predicated on expected production quantities and not on technical feasibility. Therefore, LSI technology has not been reflected in the concept. The detailed design supporting the options of Concept 1 is described in Appendix D.

5.2.2 IPC Baseband Demodulator

The RF front-end, IF amplifier, and AGC circuitry and power supplies of the VHF receiver are conventional in design and do not warrant additional definition. However, the signal output from the IF amplifier must be demodulated prior to decoding. The baseband demodulator considered in this study is designed to detect the TTL equivalent of a sine wave at frequency (e.g., 2400 Hz) and at half-frequency (e.g., 1200 Hz). In this technique a shift register clocked at eight times the operating frequency accepts the data stream, one data bit at a time, and compares the logic state in the register of the 2nd, 3rd, 6th, and 7th clock pulses. A high state in all four positions indicates a data bit at half-frequency (all logic 1), resulting in an output to the decoder of no bit change (logic 1). A combination of high and low states (logic 1100 or 0011) indicates a data bit at frequency, resulting in an output to the decoder of a bit change (logic 0). The demodulator makes use of conventional discrete components, gates, counters, and comparators, in addition to the shift register. The logic schematic is presented in Appendix D.

5.2.3 IPC Baseband Modulator

The baseband modulator, required by the duplex option of this concept, consists of an audio-frequency generation network and a switching network designed to provide differentially encoded frequency-shift-keyed baseband signals to the transmitter modulator. The frequency generator contains an oscillator that is used to provide four synchronous signals of equal amplitude at 1200 Hz and 2400 Hz, each with 0° and 180° phase shift. Data to be transmitted are processed through a differential encoder to establish the logic state (bit change or no change) of the sequential data. The state of the differential encoder controls the output switch to provide the properly phased 1200 Hz or 2400 Hz sinusoidal waveform to the transmitter modulator for transmission to ground. (For higher-data-rate applications, the oscillators would generate 2400 Hz and 4800 Hz signals, respectively.)

The modulator is solid state, using conventional integrated circuits compatible with the TTL family of discrete devices. The modulator timing diagram and logic schematic are presented in Appendix D.

5.2.4 Reply Encoder

Duplex operation under Concept 1 requires acknowledgment by the aircraft that a message has been properly received or that an error has been detected in a message apparently addressed to that aircraft. The logic processor automatically performs the acknowledgment function by storing the entire received message in shift registers and, after BCS execution, encoding the appropriate reply for transmission to the ground. Two control bits added to the received message inform the ground IPC system of the status of the command as processed by the airborne logic processor. The encoder consists of a conventional 128-bit shift register of the CMOS family and is physically located on the IPC processor cards. The logic diagram detailing encoder operation is included in the processor diagrams of Appendix D.

5.2.5 Frequency Synthesizer

The frequency synthesizer required for multi-channel operation consists of conventional crystal-controlled oscillators with solid-state amplifiers for driving the tuning stages of the receiver (and transmitter). A digital logic switching network is used to connect the appropriate oscillator stage to the system for operation at the predetermined frequencies. Altitude-banded frequency switching is accomplished by using the Grey code logic data developed by the pressure altimeter. Depending on the choice of altitude bands and limits of protection covered by the IPC computers, the control can be based on only the "A" pulses of the transmission (Grey) code or on the A, B, and D pulses of the code. A typical logic network used to convert the Grey code to switching control is detailed in Appendix D.

5.3 IPC DISPLAY

The display indicator required in support of both concepts proposed is a standard ARINC Characteristic panel-mounted ATI 3 unit for the high-performance aircraft; for the general aviation low-performance aircraft, it is an integral part of the panel-mounted avionics. Figure 5-8 shows the recommended command functions incorporated in high-performance avionics, including control and test functions; and Figure 5-9 shows the indicator as part of the panel-mounted receiver used by low-performance aircraft.

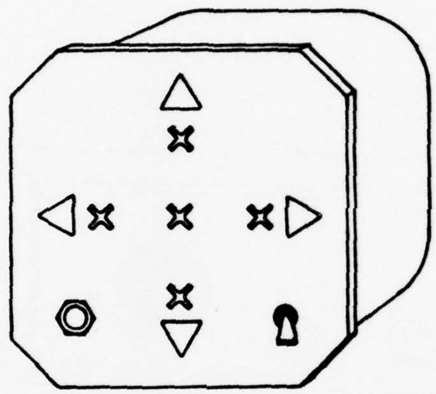

Figure 5-8. IPC COMMAND INDICATOR, HIGH-PERFORMANCE AIRCRAFT

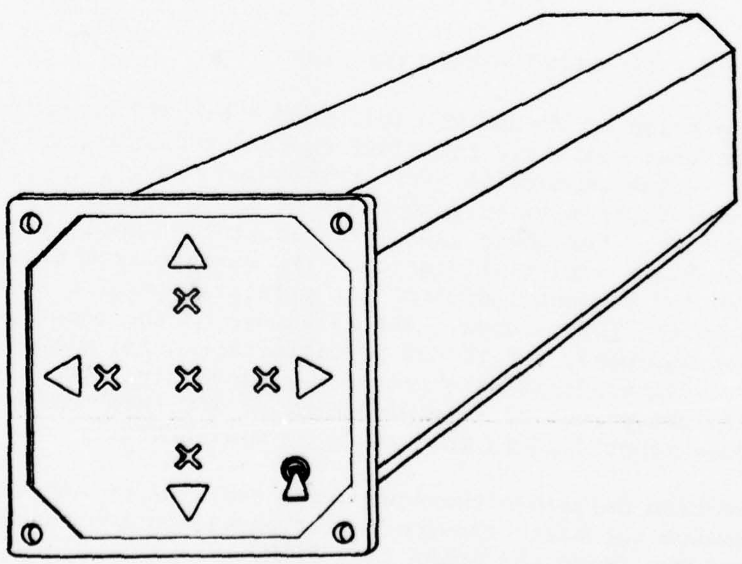

Figure 5-9. IPC RECEIVER INDICATOR, LOW-PERFORMANCE AIRCRAFT

The avionics for the options that require retransmission of the IPC data to ground computers must include the VHF transmitter. Low-performance general aviation aircraft will have avionics that incorporate all functions in a single panel-mounted enclosure typified by Figure 5-10.

The command indicator consists of a faceplate, lamps, test switch, and control switch. All electronic elements required for data decoding and lamp drivers are part of the logic processor contained in the avionics package.

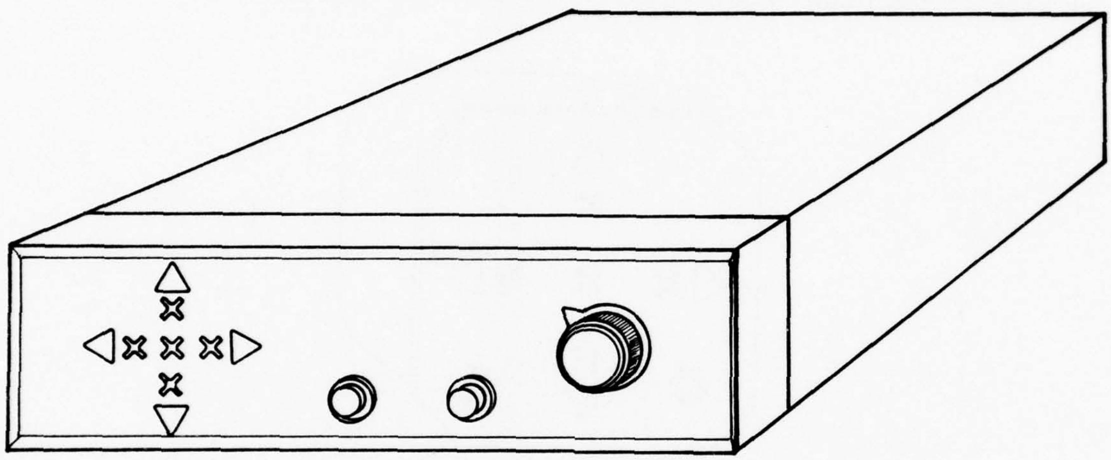

Figure 5-10. IPC TRANSCEIVER INDICATOR, LOW-PERFORMANCE AIRCRAFT

5.4 CONCEPT 2 - IPC USING ACARS DATA LINK

The adaptation of the ACARS data link to the IPC concept is practical for the users that will have the ACARS equipment as standard avionics on the aircraft -- the commercial air carriers and many of the corporate transports that constitute a large percentage of the high-performance general aviation aircraft. For these users, the adaptation would require a data processor to obtain a partially decoded IPC message from the existing ACARS modem, and an IPC command indicator for presentation of collision avoidance information to the flight crew. The remainder of the general aviation community is not equipped, and is not permitted to equip, with full-capability ACARS modems. Aircraft in this category will require modems that limit capability to reception and acknowledgment of IPC information. Such a modem has been identified in this study as Mini-ACARS.

This section describes the equipments required by air carriers and high-performance corporate transports for participation in an IPC separation-assurance program using the ACARS data link.

5.4.1 ACARS IPC Data Processor

The basic ACARS modem is designed to perform the channel-management functions necessary for selective addressing of aircraft, message destination routing, parity checks, and acknowledgment functions. The overhead characters associated with channel management in the received message are stripped from the data stream by the modem, and the formatted text is routed to an appropriate output port of the modem. There are provisions for unformatted free-text outputs on a port identified as the Optional Auxiliary Terminal (OAT). It is assumed that this port, currently unassigned, will be used as the IPC output of the modem.

The data processor assigned for IPC operation would receive IPC information from the OAT output and perform a series of logic sequences prior to the display of commands to the pilot. Figure 5-11 is a logic flow diagram of the data-reduction and decision process of the IPC processor. Each bit of data detected at the input is examined for a start-of-text character. Once the start-of-text is detected, the next 12 bits of data are extracted and checked for errors in transmission. If an error is detected, there will be no display update and an acknowledgment message, with special characters indicating an uplink error condition, will be encoded. The encoded message is buffered to the ACARS modem for transmission to the ground IPC computers, and the system is reset for the next message. If no error is detected, the processor activates the logic circuitry that corresponds to the IPC command transmitted and updates the IPC display at the pilot's console. A special-format message acknowledging the receipt of an error-free message is encoded and buffered to the ACARS modem for transmission to the ground IPC computers. The system is reset and is then ready to receive the next IPC update.

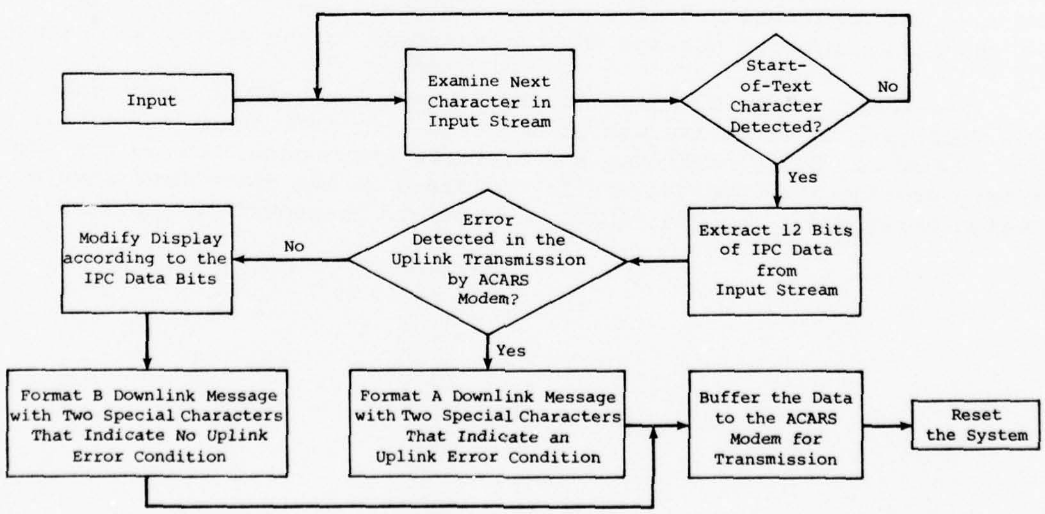

Figure 5-11. IPC USING ACARS LOGIC FLOW DIAGRAM

The logic design uses predominantly discrete components from the TTL logic family. Off-the-shelf registers, counters, and flip-flops constitute the majority of the logic components. The processor package also includes lamp drivers to control the remotely located IPC indicator display. Design details for the ACARS IPC data processor are presented in Appendix D.

5.4.2 Mini-ACARS Modem and Processor

The design of a modem and processor intended for the low-performance general aviation aircraft reflects the objective of not interfering with normal data communications of the ACARS users while still providing an efficient and low-cost avionics system that meets the requirements of IPC. The logic design supporting the Mini-ACARS concept takes advantage of the operational algorithms of ACARS; that is, it will not recognize ground polling interrogations, thereby limiting the number of replying aircraft to those equipped with ACARS, and it will decode each ground transmission, looking for key bits in the data stream that identify the message as an IPC transmission and the aircraft for which it is destined. This early decoding of an ACARS ground transmission makes the Mini-ACARS system appear as a passive receiver to all but IPC communications.

Figure 5-12 is a logic flow diagram of the decoding and decision-making process of the Mini-ACARS modem. Detected data are received from a VHF transceiver and clocked into the processors by a stable oscillator-driven clock network. The data stream is sampled one bit at a time to detect the formatted pre-key and bit-sync. The system keeps recycling until these parameters are detected. The input stream following the bit-sync is loaded into shift registers, and the data are compared with a standard format programmed into an ROM. Failure to correspond with IPC formats causes the system to reset. Recognition of an IPC message format results in further data reduction to compare aircraft identification with message designation. A block-check sequence (BCS) confirming error-free reception of the IPC message and designation results in an update of the IPC display and encoding of the acknowledgment message for transmission to the ground IPC computers.

The logic design is based on readily available logic components in the TTL family, with extensive use of MSI circuitry such as ROMs, control counters, decoders, BCS generators, and discrete components. Circuitry for IPC memory storage and lamp drivers is contained in the Mini-ACARS module. Design details for the Mini-ACARS concept are presented in Appendix D.

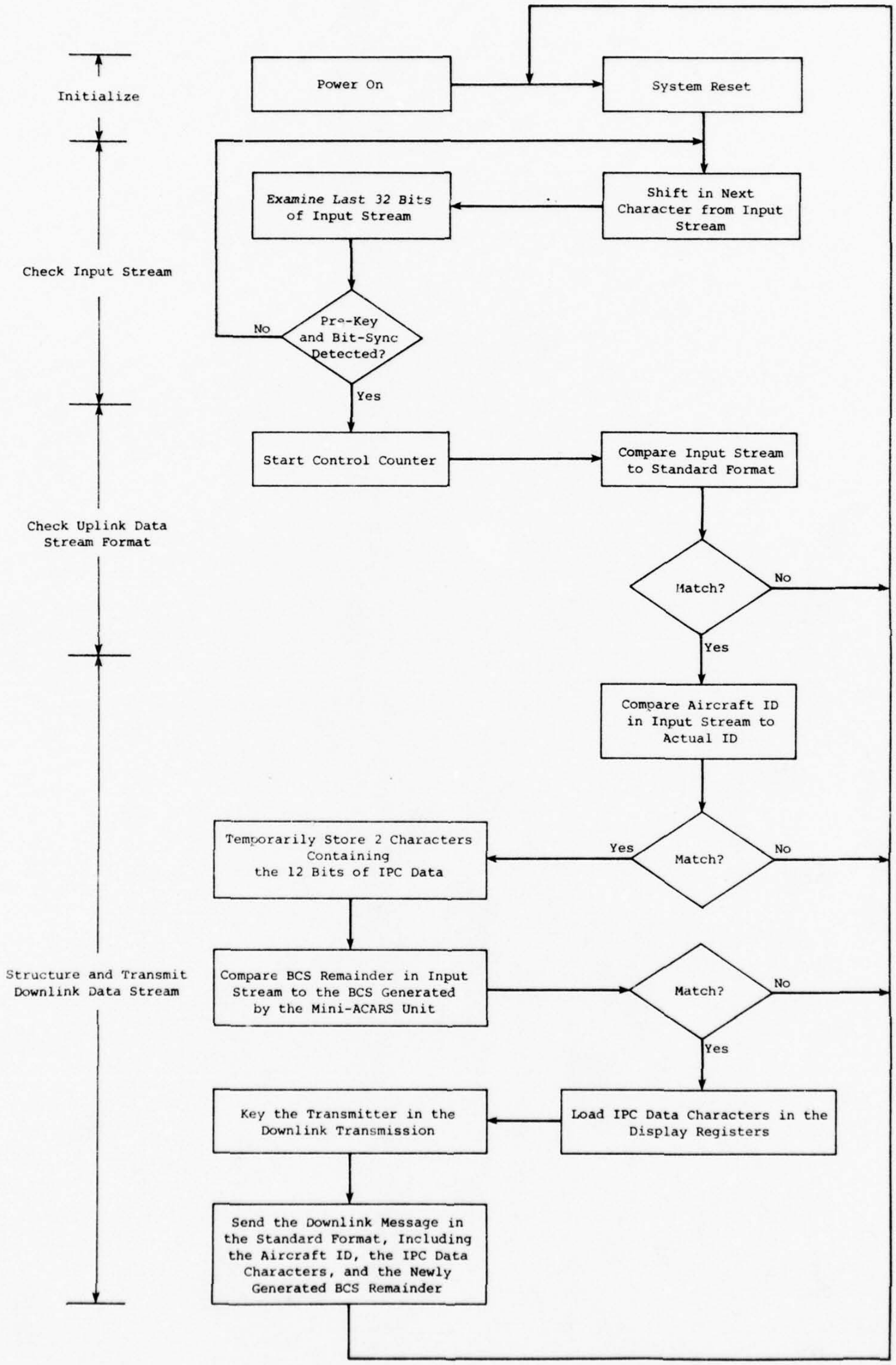

Figure 5-12. IPC USING MINI-ACARS LOGIC FLOW DIAGRAM

CHAPTER SIX

IPC AVIONICS COST DEVELOPMENT

The equipment cost data developed in this chapter provide the basis for an economic comparison of the proposed concepts -- IPC using the dedicated VHF, and IPC using ACARS. Careful development of these data was an essential step in the overall evaluation of a cost-effective collision avoidance concept.

To provide accurate data on avionics costs, it was necessary to develop detailed equipment designs based on the probable production versions of similar avionics currently available from air carrier and general aviation manufacturers. The expected quantities of production affect the cost of any avionic equipment. The total annual production quantity for a single manufacturer was established at 1000 units to realize a reasonable production-line capability and a reasonable discount in parts and material procurement. The costs developed in this chapter are based on 1975 dollars to permit comparison with the costs previously reported for other collision avoidance concepts (Reference 10). There is no requirement for advanced technology to meet any of the concepts defined in this study.

6.1 AVIONICS COST DEVELOPMENT - CONCEPT 1

The development of equipment costs presented in this section represents the adaptation of module components that are used in the manufacture and assembly of VHF transceivers and meet the requirements of the VHF IPC data link. Existing components were chosen for the following reasons:

- Direct adaptability to the electrical requirements specified for a VHF data link
- Cost-effectiveness in the use of components that have already been subjected to the learning-curve effect of new equipment development

The equipment chosen as a base for development of the VHF data link was that which exhibited the highest promise of operating satisfactorily, reflected standard current technology, and was within the capability of all major manufacturers of airborne VHF transceivers. Circuit modifications were made, and additional circuits (e.g., logic processor and demodulator) were incorporated to provide the required operational design. The

resultant design identified the component parts (by part number) in the quantities required to estimate system procurement costs, assembly labor costs, and manufacturing costs. Component parts costs are presented for each version in Appendix E.

6.1.1 High-Performance Aircraft Avionics

The equipment required by all the certified air carriers and most of the high-performance general aviation aircraft was designed to meet the expected specifications of ARINC Characteristics and the environmental requirements of the Radio Technical Commission for Aeronautics (RTCA) Document No. DO-160, as applicable to air carrier VHF transceivers.

Tables 6-1 through 6-4 identify all major modules required for assembly of the four options considered and give the total costs of material, labor, burden, inspection, and production engineering, which constitute the direct cost of manufacturing the subassemblies. The direct cost of manufacture is identified in the tables as the factory cost. A 20 percent general and administrative cost and a 15 percent profit were added to the factory costs to establish the estimated minimum selling price. This selling price would be the acquisition cost borne by a commercial air carrier or by an avionics distributor who resells these systems to the small percentage of general aviation users requiring high-performance avionics. The cost to these users is identified in the tables by both module and system list price.

The costs developed vary between the options presented because of the increasing complexity of the options, from the single-channel receive-only system (Table 6-1) through the four-channel full-duplex system (Table 6-4). Each system, however, provides the same IPC information to the pilot, and its increased complexity is justified by the performance requirements stated in earlier chapters of this report.

6.1.2 Low-Performance Aircraft Avionics

The general-aviation version of the VHF IPC data link equipment was subjected to a pricing evaluation similar to that used for the high-performance units. The packaging of these units is unrestricted, conforming to the practice in the general aviation community, and the environmental requirements reflect the less stringent specifications of Document DO-160, as applicable to the general aviation class of equipment. Tables 6-5 through 6-8 identify the major modules required for assembly of each of the four options considered and give the total cost of material, labor, and mark-up for overhead, general and administrative, and profit. The resultant cost is the manufacturer's selling price to distributors, who resell these systems to the general aviation users. The advertised list price of the systems would include a 100 percent distribution mark-up, and this is shown for the system costs in the tables.

Table 6-1. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF SINGLE CHANNEL, UPLINK ONLY, HIGH-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars										
	Pre-Selector	IF Coupler	IF Amplifier	Select Attenuator	AGC Board	Power Supply	Logic Decoder 1	Logic Decoder 2	Chassis	Assembly and Test	Totals
Material Cost	44.79	2.65	11.99	7.29	14.02	38.66	185.03	102.21	81.41	-	488.05
Material Handling (25%)	11.20	0.66	3.00	1.82	3.51	9.67	46.26	25.55	20.35	-	122.02
Labor ($11.00 per hour)	8.06	2.73	9.76	7.02	6.64	22.52	19.59	22.33	19.21	29.43	147.29
Burden (135% Labor)	10.88	3.69	13.17	9.48	8.97	30.40	26.45	30.15	25.93	39.72	198.84
Inspection (5% Labor/Burden)	0.95	0.32	1.15	0.83	0.78	2.65	2.30	2.62	2.26	3.46	17.32
Subtotal	75.88	10.05	39.07	26.44	33.92	103.90	279.63	182.86	149.16	72.61	973.52
Engineering and Quality Control (25%)	18.97	2.51	9.77	6.61	8.48	25.98	69.91	45.72	37.29	18.15	243.39
Factory Cost	94.85	12.56	48.84	33.05	42.40	129.88	349.54	228.58	186.45	90.76	1216.91
G&A (20%)	18.97	2.51	9.77	6.61	8.48	25.98	69.91	45.72	37.29	18.15	243.39
Total Direct Cost	113.82	15.07	58.61	39.66	50.88	155.86	419.45	274.30	223.74	108.92	1460.31
Profit (15%)	17.07	2.26	8.79	5.95	7.63	23.38	62.92	41.14	33.56	16.34	219.04
Selling Price	130.89	17.33	67.40	45.61	58.51	179.24	482.37	315.44	257.30	125.26	1679.35
Distribution (30%)	39.27	5.20	20.22	13.68	17.55	53.77	144.71	94.63	77.19	37.58	503.80
List Price	170.16	22.53	87.62	59.29	76.06	233.01	627.08	410.07	334.49	162.84	2183.15

Table 6-2. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED, VHF SINGLE CHANNEL, DUPLEX, HIGH-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars										
	Pre-Selector	IF Coupler	IF Amplifier	Select Attenuator	AGC Board	Power Supply	Logic Decoder 1	Logic Decoder 2	Transmitter	Chassis	Assembly and Test	Totals
Material Cost	44.79	2.65	11.99	7.29	20.88	129.19	196.28	102.21	75.96	149.14	-	740.38
Material Handling (25%)	11.20	0.66	3.00	1.82	5.22	32.30	49.07	25.55	18.99	37.29	-	185.10
Labor ($11.00 per hour)	8.06	2.73	9.76	7.02	7.55	29.97	19.76	22.33	10.89	23.45	40.98	182.50
Burden (135% Labor)	10.88	3.69	13.17	9.48	10.19	40.46	26.67	30.15	14.70	31.66	55.32	246.37
Inspection (5% Labor/Burden)	0.95	0.32	1.15	0.83	0.89	3.52	2.32	2.62	1.28	2.76	4.81	21.45
Subtotal	75.88	10.05	39.07	26.44	44.73	235.44	294.10	182.86	121.82	244.30	101.11	1375.80
Engineering and Quality Control (25%)	18.97	2.51	9.77	6.61	11.18	58.86	73.53	45.72	30.46	61.08	25.28	343.97
Factory Cost	94.85	12.56	48.84	33.05	55.91	294.30	367.63	228.58	152.28	305.38	126.39	1719.77
G&A (20%)	18.97	2.51	9.77	6.61	11.18	58.86	73.53	45.72	30.46	61.08	25.28	343.97
Total Direct Cost	113.82	15.07	58.61	39.66	67.09	353.16	441.16	274.30	182.74	366.46	151.67	2063.74
Profit (15%)	17.07	2.26	8.79	5.95	10.06	52.97	66.17	41.14	27.41	54.97	22.75	309.54
Selling Price	130.89	17.33	67.40	45.61	77.15	406.13	507.33	315.44	210.15	421.43	174.42	2373.28
Distribution (30%)	39.27	5.20	20.22	13.68	23.14	121.84	152.20	94.63	63.04	126.43	52.32	711.97
List Price	170.16	22.53	87.62	59.29	100.29	527.97	659.53	410.07	273.19	547.86	226.74	3085.25

Table 6-3. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF MULTI-CHANNEL, UPLINK ONLY, HIGH-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars											
	Pre-Selector	IF Coupler	IF Amplifier	Select Attenuator	AGC Board	Power Supply	Logic Decoder 1	Logic Decoder 2	Frequency Control	Chassis	Assembly and Test	Totals
Material Cost	49.91	2.65	11.99	7.29	7.16	38.66	185.03	102.21	78.13	83.08	-	566.11
Material Handling (25%)	12.48	0.66	3.00	1.82	1.79	9.67	46.26	25.55	19.53	20.77	-	141.53
Labor ($11.00 per hour)	8.06	2.73	9.76	7.02	5.73	22.52	19.59	22.33	12.46	19.37	30.50	160.07
Burden (135% Labor)	10.89	3.69	13.17	9.48	7.74	30.40	26.45	30.15	16.82	26.15	41.21	216.15
Inspection (5% Labor/Burden)	0.95	0.32	1.15	0.83	0.67	2.65	2.30	2.62	1.46	2.28	3.59	18.82
Subtotal	82.29	10.05	39.07	26.44	23.09	103.90	279.63	182.86	128.40	151.65	75.30	1102.68
Engineering and Quality Control (25%)	20.57	2.51	9.77	6.61	5.77	25.98	69.91	45.72	32.10	37.91	18.83	275.68
Factory Cost	102.86	12.56	48.84	33.05	28.86	129.88	349.54	228.58	160.50	189.56	94.13	1377.75
G&A (20%)	20.57	2.51	9.77	6.61	5.77	25.98	69.91	45.72	32.10	37.91	18.83	275.68
Total Direct Cost	163.43	15.07	58.61	39.66	34.63	155.86	419.45	274.30	192.60	227.47	112.96	1653.43
Profit (15%)	18.52	2.26	8.79	5.95	5.20	23.38	62.92	41.14	28.89	34.12	16.94	248.01
Selling Price	141.95	17.33	67.40	45.61	39.83	179.24	482.37	315.44	221.49	261.59	129.90	1901.44
Distribution (30%)	42.59	5.20	20.22	13.68	11.95	53.77	144.71	94.63	66.45	78.48	38.97	570.44
List Price	184.54	22.53	87.62	59.29	51.78	233.01	627.08	410.07	287.94	340.07	168.87	2472.80

Table 6-4. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF MULTI-CHANNEL, DUPLEX, HIGH-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars												
	Pre-Selector	IF Coupler	IF Amplifier	Select Attenuator	AGC Board	Power Supply	Logic Decoder 1	Logic Decoder 2	Transmitter	Frequency Control	Chassis	Assembly and Test	Totals
Material Cost	49.91	2.65	11.99	7.29	7.16	129.19	196.28	102.21	75.96	107.13	149.14	-	838.91
Material Handling (25%)	12.48	0.66	3.00	1.82	1.79	32.30	49.07	25.55	18.99	26.78	37.29	-	209.73
Labor ($11.00 per hour)	8.06	2.73	9.76	7.02	5.73	29.97	19.76	22.33	10.89	18.16	23.45	42.08	199.94
Burden (135% Labor)	10.89	3.69	13.17	9.48	7.74	40.46	26.67	30.15	14.70	24.52	31.66	56.80	269.93
Inspection (5% Labor/Burden)	0.95	0.32	1.15	0.83	0.67	3.52	2.32	2.62	1.28	2.13	2.76	4.94	23.49
Subtotal	82.29	10.05	39.07	26.44	23.09	235.44	294.10	182.86	121.82	178.72	244.30	103.82	1542.00
Engineering and Quality Control (25%)	20.57	2.51	9.77	6.61	5.77	58.86	73.53	45.72	30.46	44.68	61.08	25.96	385.52
Factory Cost	102.86	12.56	48.84	33.05	28.86	294.30	367.63	228.58	152.28	223.40	305.38	129.78	1927.52
G&A (20%)	20.57	2.51	9.77	6.61	5.77	58.86	73.53	45.72	30.46	44.68	61.08	25.96	385.52
Total Direct Cost	123.43	15.07	58.61	39.66	34.63	353.16	441.16	274.30	182.74	268.08	366.46	155.74	2313.04
Profit (15%)	18.52	2.26	8.79	5.95	5.20	52.97	66.17	41.14	27.41	40.21	54.97	23.36	346.95
Selling Price	141.95	17.33	67.40	45.61	39.83	406.13	507.33	315.44	210.15	308.29	421.43	179.10	2659.99
Distribution (30%)	42.59	5.20	20.22	13.68	11.95	121.84	152.20	94.63	63.04	92.49	126.43	53.73	798.00
List Price	184.54	22.53	87.62	59.29	51.78	527.97	659.53	410.07	273.19	400.78	547.86	232.83	3457.99

Table 6-5. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF SINGLE CHANNEL, UPLINK ONLY, LOW-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars					
	Receivers	Leveling Board/ Power Supply	Logic Decoder 1	Logic Decoder 2	Chassis	Totals
Material Cost	51.38	12.69	61.21	25.18	12.42	162.88
Material Handling (10%)	5.14	1.27	6.12	2.52	1.24	16.29
Labor ($3.25 per hour)	6.38	7.02	5.79	6.60	11.31	37.10
Subtotal	62.90	20.98	73.12	34.30	24.97	216.27
Overhead, G&A, and Profit (67%)	42.14	14.06	48.99	22.98	16.73	144.90
Factory Selling Cost	105.04	35.04	122.11	57.28	41.70	361.17
			Distributor Mark-Up (100%)			361.17
			List Price			722.34

Table 6-6. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF SINGLE CHANNEL, DUPLEX, LOW-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars						
	Receiver	Leveling Board/ Power Supply	Logic Decoder 1	Logic Decoder 2	Transmitter Modulator	Chassis	Totals
Material Cost	55.87	12.69	67.46	25.18	52.50	19.72	233.42
Material Handling (10%)	5.59	1.27	6.75	2.52	5.25	1.97	23.35
Labor ($3.25 per hour)	6.54	7.02	5.84	6.60	6.90	14.27	47.17
Subtotal	68.00	20.98	80.05	34.30	64.65	35.96	303.94
Overhead, G&A, and Profit (67%)	45.56	14.06	53.63	22.98	43.32	24.09	203.64
Factory Selling Cost	113.56	35.04	133.68	57.28	107.97	60.05	507.58
Distributor Mark-Up (100%)							507.58
List Price							1015.16

Table 6-7. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF MULTI-CHANNEL, UPLINK ONLY, LOW-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollar						
	Receiver	Leveling Board/ Power Supply	Frequency Control	Logic Decoder 1	Logic Decoder 2	Chassis	Totals
Material Cost	46.59	12.69	45.12	61.21	25.18	13.07	203.86
Material Handling (10%)	4.66	1.27	4.51	6.12	2.52	1.31	20.39
Labor ($3.25 per hour)	6.05	7.02	4.66	5.79	6.60	11.39	41.51
Subtotal	57.30	20.98	54.29	73.12	34.30	25.77	265.75
Overhead, G&A, and Profit (67%)	38.39	14.06	36.37	48.99	22.98	17.27	178.06
Factory Selling Cost	95.69	35.04	90.66	122.11	57.28	43.04	443.82
Distributor Mark-Up (100%)							443.82
List Price							887.64

Table 6-8. SYSTEM COST DEVELOPMENT: IPC USING DEDICATED VHF MULTI-CHANNEL, DUPLEX, LOW-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars							
	Receiver	Leveling Board/ Power Supply	Frequency Control	Logic Decoder 1	Logic Decoder 2	Transmitter Modulator	Chassis	Totals
Material Cost	46.59	12.69	62.96	67.46	25.18	52.50	20.32	287.70
Material Handling (10%)	4.66	1.27	6.30	6.75	2.52	5.25	2.03	28.77
Labor ($3.25 per hour)	6.05	7.02	5.37	5.84	6.60	6.90	14.51	52.29
Subtotal	57.30	20.98	74.63	80.05	34.30	64.65	36.86	368.77
Overhead, G&A, and Profit (67%)	38.39	14.06	50.00	53.63	22.98	43.32	24.70	274.08
Factory Selling Cost	95.69	35.04	124.63	133.68	57.28	107.97	61.56	615.85
Distributor Mark-Up (100%)								615.85
List Price								1231.70

The operational concept of the low-performance systems is identical to that proposed for the high-performance avionics, with the exception that the receivers have lower sensitivities and the transmitters have lower power outputs, consistent with the existing VHF communications avionics in service. The proposed multi-channel (four-frequency) option is intended for use at all altitudes. One of the four possible divisions would probably be at 20,000 feet. The typical general aviation aircraft equipped with the low-performance avionics normally does not reach this altitude and would not require the full complement of frequencies. However, the equipment costs for this option reflect the full capability of operation, allowing use of these equipments at all altitudes where present general aviation transceivers are used.

6.2 IPC COMMAND INDICATOR

The tactical command indicator used in the IPC concept is a standard ARINC-specification ATI unit designed for mounting in the instrument panel of an aircraft. A set of nine lights, displaying arrows and X's, provides the pilot with tactical commands for horizontal or vertical escape maneuvers when the aircraft is on a collision course with any other nearby aircraft.

All air carrier and general aviation high-performance aircraft using ARINC-specification type avionics will require a separately mounted IPC indicator. In low-performance aircraft, the command indicator is incorporated in the faceplate of the avionics. Indicator costs for low-performance aircraft were included in the avionics costs of Tables 6-5 through 6-8.

Table 6-9 presents the cost development of the high-performance aircraft command indicator. The same methodology used in estimating the selling price of high-performance avionics has been applied to the indicator, resulting in the selling price to commercial air carriers and distributors and the list price expected to be paid by the individual owners of high-performance aircraft. The detailed parts lists, component costs, and assembly estimates are included in Appendix E.

6.3 AVIONICS COST DEVELOPMENT - CONCEPT 2

The equipment cost development presented in this section assumes the existence of VHF transceivers capable of providing data at baseband frequencies to signal-processing equipment, an ACARS data modem for the high-performance aircraft, and panel space in the consoles of low-performance general aviation aircraft for installation of a Mini-ACARS modem with built-in indicator. The cost estimating method is the same as that described in Section 6.1 for Concept 1. The avionics are designed for use by either the high-performance aircraft or the low-performance aircraft. Component parts quantities and costs supporting each class of avionics are presented in Appendix E.

Table 6-9. COST DEVELOPMENT OF IPC COMMAND INDICATOR, HIGH-PERFORMANCE AIRCRAFT	
Cost Element	Cost (Dollars)
Material	26.35
Material Handling (25%)	6.59
Labor ($11.00 per hour)	22.33
Burden (135% of labor)	30.15
Inspection (5% labor and burden)	2.62
Subtotal	88.04
Engineering and Quality Control (25%)	22.01
Factory Cost	110.05
G&A (20%)	22.01
Total Direct Cost	132.06
Profit (15%)	19.81
Selling Price	151.87
Distribution (30%)	45.56
List Price	197.43

6.3.1 High-Performance Aircraft Avionics

The equipment required by all the certified air carriers and most of the high-performance general aviation aircraft was designed to meet the expected requirements of ARINC Characteristics and the environmental requirements of RTCA. Table 6-10 identifies the major modules required to assemble the IPC data processor used in conjunction with the ACARS modem to provide IPC information to the flight crew. The cost development of each module and the avionics package uses the cost elements associated with production and management of the equipment. The data processor is expected to be housed in a standard 1/4-ATR ARINC enclosure and contain all functions (e.g., decoding, lamp driver circuits, power supplies) necessary to provide the IPC information. Designed for remote installation in an aircraft's electronic bay, the system must be supplemented with a commercial indicator identical to that described in Section 6.2. The selling price of $1,055 reflects the expected cost to the air carriers, the list price of $1,371 being applicable to the individual aircraft owner.

Table 6-10. SYSTEM COST DEVELOPMENT: IPC USING ACARS, HIGH-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars					
	Logic Decoder 1	Logic Decoder 2	Power Supply	Chassis	Assembly and Test	Totals
Material Cost	61.04	154.10	42.96	35.48	-	293.58
Material Handling (25%)	15.26	38.53	10.74	8.87	-	73.40
Labor ($11.00 per hour)	18.58	19.89	18.57	14.31	27.72	99.07
Burden (135% Labor)	25.08	26.85	25.07	19.32	37.42	133.74
Inspection (5% Labor/Burden)	2.18	2.34	2.18	1.68	3.26	11.64
Subtotal	122.14	241.71	99.52	79.66	68.40	611.43
Engineering and Quality Control (25%)	30.54	60.43	24.88	19.92	17.10	152.87
Factory Cost	152.68	302.14	124.40	99.58	85.50	764.30
G&A (20%)	30.54	60.43	24.88	19.92	17.10	152.87
Total Direct Cost	183.22	362.57	149.28	119.50	102.60	917.17
Profit (15%)	27.48	54.38	22.39	17.92	15.39	137.56
Selling Price	210.70	416.95	171.67	137.42	117.99	1054.73
Distribution (30%)	63.21	125.08	51.50	41.23	35.40	316.42
List Price	273.91	542.03	223.17	178.65	153.39	1371.15

6.3.2 Low-Performance Aircraft Avionics

The avionics describing the Mini-ACARS concept have been designed to conform with the general aviation practice of packaging in a single enclosure suitable for mounting in the control panel of the aircraft. Table 6-11 shows the results of the cost estimation for a unit similar to the configuration shown in Figure 5-10, but with a seven-position thumb-wheel switch for aircraft-identity input. The unit, meeting the environmental requirements of RTCA DO-160 applicable to general aviation equipment, contains all the signal processing and display electronics required to interface with a VHF transceiver for data acquisition and the front-panel indicators for IPC command presentation. The factory selling price of $297 has been marked up to the expected list price of $593 the individual low-performance-aircraft owner would be required to pay to acquire the unit.

6.4 SUMMARY OF AVIONICS COSTS

This chapter has presented the development of the cost of avionics that must be manufactured to support any of the concepts, with associated options, developed in the study. Because the hybrid case draws from the general aviation designs of Concept 1 and the air carrier designs of Concept 2, no separate cost presentation for this option is required.

The costs presented are for unit production in medium to large volume, without design, development, or start-up costs. The addition of these nonrecurring costs to the unit costs could result in expected acquisition prices that are misleading since amortization is heavily dependent on the market demand and on annual production. Amortization is intentionally omitted from the costs to the air carriers and the private aircraft owners presented in summary form in Table 6-12 for Concept 1 and Table 6-13 for Concept 2, to facilitate comparison with costs developed for alternative concepts.

Table 6-12 details the cost of avionics acquisition to each of the three users identified in the study. An additional potential user, the Military Airlift Command, would require the same avionics as the air carriers, and it has been included in that category. The cost of antennas, necessary for most aircraft installations, has been added to identify the entire equipment cost supporting each of the four options of Concept 1 for providing IPC information over a dedicated VHF data link.

Table 6-13 presents comparable system acquisition costs to the three users for the implementation of IPC over the privately owned ACARS network.

Both tables present the cost of a single (nonredundant) system with one command indicator per aircraft. The air carriers' practice of achieving high operational availability through system redundancy would require additional avionics and indicators, with the antennas probably being switched between the systems. Sufficient information is presented in the tables to permit configuration costing of all three VHF IPC concepts.

Table 6-11. SYSTEM COST DEVELOPMENT: IPC USING MINI-ACARS, LOW-PERFORMANCE AIRCRAFT

Cost Element	Module Cost in Dollars					
	Logic Decoder 1	Logic Decoder 2	Power Supply	Chassis	Assembly and Test	Totals
Material Cost	21.70	87.52	14.47	14.97	-	138.66
Material Handling (10%)	2.17	8.75	1.45	1.50	-	13.87
Labor ($3.25 per hour)	5.46	5.93	3.04	4.11	6.57	25.11
Subtotal	29.33	102.20	18.96	20.58	6.57	177.64
Overhead, G&A, and Profit (67%)	19.65	68.47	12.70	13.79	4.40	119.01
Factory Selling Cost	48.98	170.67	31.66	34.37	10.97	296.65
Distributor Mark-Up (100%)						296.65
List Price						593.30

Table 6-12. COST SUMMARY FOR CONCEPT 1

Equipment	Configuration Option Costs (Dollars per Aircraft)			
	Single-Channel Uplink Only	Single-Channel Duplex	Four-Channel Uplink Only	Four-Channel Duplex
Air Carrier and Selected Military Aircraft				
Avionics Unit	1679	2373	1901	2660
IPC Display	152	152	152	152
Antenna	180	360	180	360
Total	2011	2885	2233	3172
High-Performance General Aviation				
Avionics Unit	2183	3085	2473	3458
IPC Display	197	197	197	197
Antenna	240	480	240	480
Total	2620	3762	2910	4135
Low-Performance General Aviation				
Avionics Unit	722	1015	887	1232
Antenna	16	32	16	32
Total	738	1047	903	1260

Note: Data from manufacturers' published price lists.

Table 6-13. COST SUMMARY FOR CONCEPT 2

Equipment	Avionics Cost per Aircraft (Dollars)
Air Carrier and Selected Military Aircraft	
Signal Processor	1055
IPC Display	152
Total	1207
High-Performance General Aviation	
Signal Processor	1371
IPC Display	197
Total	1568
Low-Performance General Aviation	
Mini-ACARS with Display	593

The IPC implementation options were discussed in Chapter Four, and data link design requirements were summarized in Table 4-6. System performance was shown to be sensitive to various bit rates and equipment characteristics, as identified by parameter sets A through C in Table 4-6. In the cost development presented in this chapter, it was assumed that bit rates affect only the oscillator designs and have no influence on manufacturing costs. Since avionics required by Concept 1 (IPC using dedicated VHF) would be new or of the latest design, the more stringent carrier rise times (CRT) and AGC settling times were considered in the choice of existing avionic modules and newly designed functions of the equipment.

Tables 6-12 and 6-13 present the acquisition costs for Concepts 1 and 2. The hybrid concept discussed in Chapter Four -- IPC using ACARS for the air carriers and selected high-performance general aviation, and IPC using dedicated VHF for the remainder of the aviation community -- requires equipments peculiar to each concept. Sufficient data are presented in the summary tables to allow configuration costing of the hybrid concept.

CHAPTER SEVEN

EVALUATION OF IPC VHF DATA LINK CONCEPTS FOR INTERIM AND LONG-TERM SERVICE

The various IPC VHF data link options and the associated avionics cost developments have been formulated on the basis of the needs of the various aviation communities and the expected traffic densities. In this chapter the introduction of IPC by means of VHF data links is evaluated as a short-term option pending deployment of DABS/IPC concepts and as a permanent solution for separation assurance. With the near-term option, it is necessary to consider only the equipment availability and system capacity projections through the mid-1980s. For permanent adoption of the IPC VHF concept, it is necessary to consider future aviation growth and expected system capacities through the end of this century.

This chapter reviews the various IPC VHF options presented in this study and evaluates the performance of each option as a function of near-term and long-term aircraft-handling capability. Equipment acquisition costs are presented for each option to provide insight into economic impact. However, the total cost of system implementation is not presented, because it would be necessary to consider installation and maintenance of both airborne and ground equipments, which are not a part of this study.

7.1 PERFORMANCE EVALUATION CRITERIA

This section sets forth the criteria and assumptions used in evaluating both the near-term and long-term capability and performance of each IPC option. In addition to providing the levels of IPC traffic associated with near-term and long-term system use, it states the performance thresholds used to evaluate each of the options.

During the initial stages of IPC implementation, the principal system users are expected to be commercial air carrier, military air transport, and selected high-performance general aviation aircraft. Only a small percentage of privately owned low-performance general aviation aircraft are expected to participate. The population of initial IPC system users will not represent a majority of the aircraft operating in any area during the 1980s. Therefore, it is assumed that for the near-term IPC equipment will be installed on 45 percent of the aircraft of the peak traffic load represented by the 1982 Los Angeles Basin model (Chapter Four).

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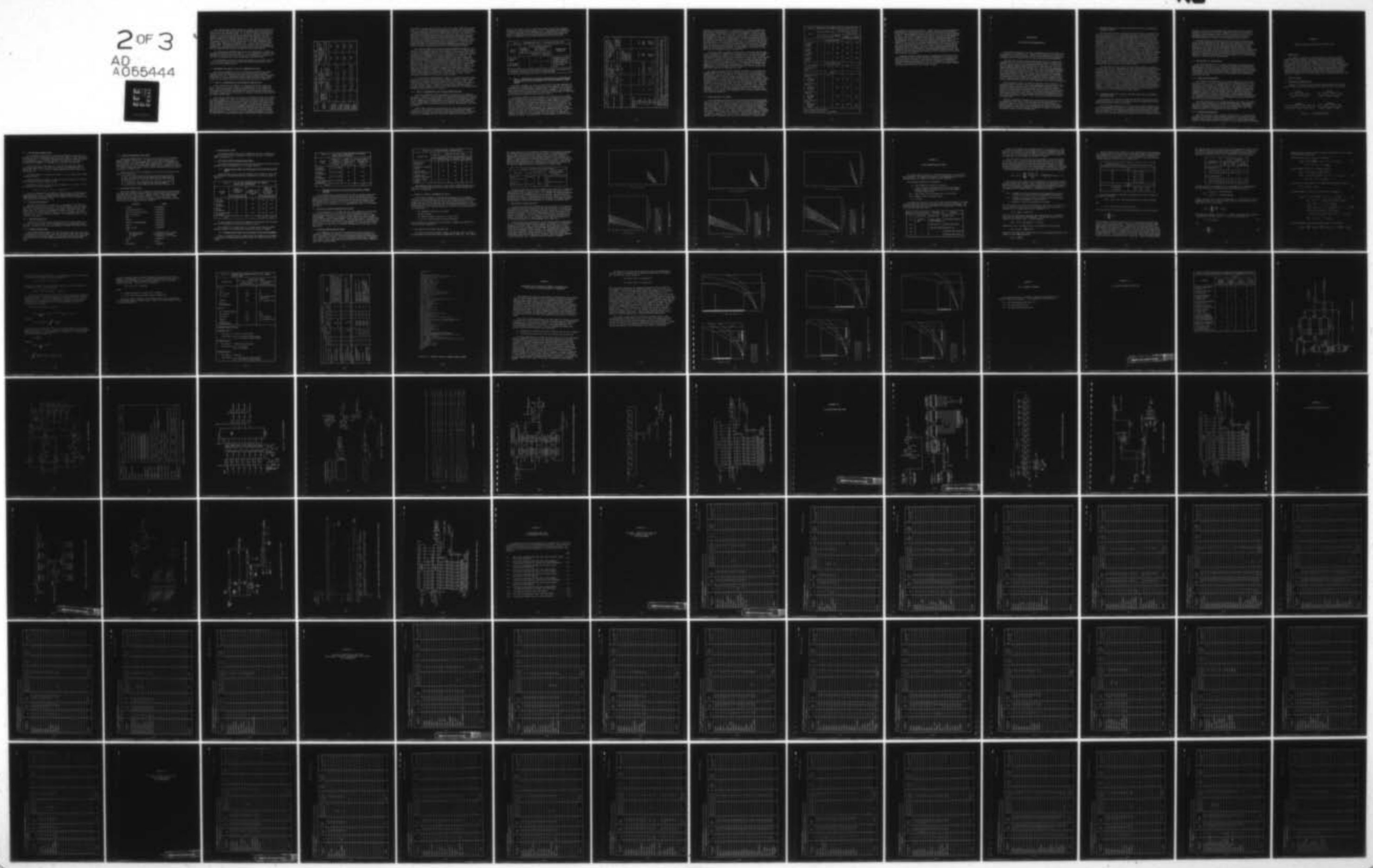

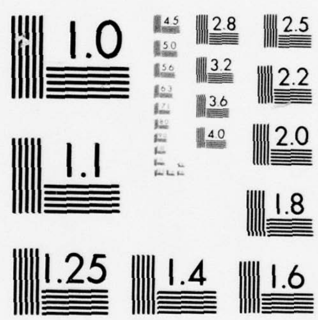

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The communications volume necessary to provide separation assurance to this level of IPC-equipped aircraft is the assumed typical workload for an interim, near-term IPC VHF system. If, on the other hand, the IPC VHF options are to be long-term solutions to separation assurance, they must be capable of sustaining significantly higher aircraft densities and much greater numbers of IPC-equipped system users. The capacity of the IPC VHF data links to provide long-term service to the aviation communities must be measured against the density projections of the 1995 Los Angeles Basin traffic model (summarized in Reference 11). In this worst-case aircraft-density model, the expected excess of 1,000 aircraft, all IPC-equipped, is assumed to be representative of the heavier traffic densities and therefore heavier communications workloads through the end of this century.

For computing the maximum traffic that can be handled by a system, two performance thresholds have been applied. It is assumed that the data link equipment can sustain duty cycles up to, but not exceeding, 70 percent and that the IPC messages must not be delayed more than two seconds.

The performance evaluation criteria described here are used in Section 7.2 to derive and compare the near-term and long-term capability of the various IPC VHF system concepts.

7.2 PERFORMANCE EVALUATION OF THE IPC IMPLEMENTATION CASES

This section addresses each of the proposed IPC VHF data link implementation cases and computes the near-term and long-range performance capabilities of each. Accompanying tables indicate numerically the expected performance of the IPC VHF system concepts under near-term traffic loads, as well as the aircraft density at which system saturation is expected.

7.2.1 Case 1 - Implementation of Dedicated IPC VHF Data Link

Case 1 entails the development of a dedicated data link, either one way or duplex, exclusively to handle the transmission of IPC command messages. The implementation options presented for Case 1 have allowed for the segmenting of airspace horizontally by altitude bands and the assigning of discrete frequencies to each band in an attempt to ensure growth potential and reduce channel usage.

The study has shown that all options of the dedicated data links exhibit an interim capability -- that is, the ability to service a level of 45 percent IPC-equipped aircraft from the peak aircraft density predicted by the 1982 Los Angeles Basin traffic model. Table 7-1 presents the interim operating characteristics and long-term capability possible through use of a system constrained by the required equipment parameters listed in Table 4-6. The typical 1980s operating characteristics are obtained from the channel-capacity curves of Chapter Four at the 800-aircraft level with 45 percent IPC-equipped and are in accordance with the equipment parameter set stated. The four-channel altitude-banded concepts assume channel operating regions

Table 7-1. IMPLEMENTATION CASE 1 - DEDICATED IPC VHF DATA LINK

System Concept	Equipment Parameter Set (See Table 4-6)	Typical 1980s Operating Characteristics (per channel)		Maximum Load Capability (Effective Number of Aircraft)	
		Utilization (Percent)	Delay Time (Seconds)	Per Channel	Per System
Single Channel, One Way	C	$\rho = 25$	$t = 0.40$	925	925
Four Channel, One Way	B	$12 \leq \rho \leq 29$	$0.42 \leq t < 0.70$	735	2450
Single Channel, Duplex	C	$\rho = 18$	$t = 0.28$	1065	1065
Four Channel, Duplex	A	$10 \leq \rho \leq 26$	$0.37 \leq t < 0.59$	780	2600

of between 30 percent and 75 percent of the total 1980s communications workload. As in the altitude-banding discussions of Chapter Four and Appendix C, these percentages include both communications for conflict resolution and redundant communications due to overlap in band coverage. The lower and upper limits of channel operation are, respectively, equivalent to an even division of the communications workload (accomplished through nonuniform allocation of altitude bands) and to the more practical allocation of altitude bands that results in greater usage of the lower-altitude-band channel than the higher-altitude-band channels (see Appendix C). It is for this reason that Table 7-1 states only probable maximums and minimums for the typical operating characteristics for the altitude-banding concepts.

The effective number of aircraft at which maximum load capability is reached is also obained from the channel-capacity curves. In single-channel concepts, this maximum capability is arrived at by an extrapolation of the 100 percent IPC-equipped curve until it surpasses one or both of the desired communications requirements (70 percent utilization or 2 seconds). In altitude-banding concepts, the effective number of aircraft is obtained through interpretation of the channel-capacity curves, which relates the total level of communications throughput to an expected level of per-channel communications. In interpreting the channel-capacity curves, it is assumed that each channel has a utilization rate of 70 percent and is handling 30 percent of the communications load (an optimal system state). This is the basis for calculating the effective number of aircraft generating this communications load per channel. In determining the effective number of aircraft per system, it is necessary to account for the fact that 5 percent of the channel communications are due to the overlap in bands, causing redundant transmissions to aircraft in those regions.

As a long-term IPC implementation, Table 7-1 indicates that the single-channel uplink one-way concept must be eliminated because of insufficient capability in probable worst-case traffic areas of the late 1990s. The single-channel duplex concept provides only a slight increase in capability over the one-way concept. However, the multi-channel altitude-banding concepts exhibit capability sufficient to handle expected peak communications workloads through the turn of the century.

7.2.2 Case 2 - Implementation of IPC Using ACARS Data Link

IPC on the ACARS data link was proposed to provide to the commercial air carrier industry a near-term method of separation assurance and collision avoidance over existing flight paths. The extension of this option to transmit IPC commands to non-ACARS members, as well as IPC and ACARS communications to ACARS members, was based on the assumption that the proper interface procedures and cooperation between the FAA and ACARS members could also be achieved.

Typical 1980s operating characteristics for this option were based on a density of 800 aircraft, 40 percent receiving IPC through mini-ACARS avionics and 5 percent receiving IPC through the ACARS avionics. The capability of an IPC/ACARS data link under this communications workload was

found to be suitable only for short-term interim use and only following modification of the proposed ACARS bit rate. The maximum load capability is heavily dependent on the percentage mix of ACARS and IPC traffic and would be unacceptable under expected long-term communications workload. Table 7-2 summarizes the data link characteristics of this option.

Table 7-2. IMPLEMENTATION CASE 2 - IPC/ACARS VHF DATA LINK

System Concept	Equipment Parameter Set (See Table 4-6)	Typical 1980s Operating Characteristics (per channel)*		Maximum Load Capability
		Utilization (Percent)	Delay Time (Seconds)	
IPC Using ACARS	C	$\rho = 45$	$\rho = 0.47$	Dependent on number of ACARS users; expected growth potential very limited (see Figure 4-12).
IPC Using Mini-ACARS	C			

*Represents operating characteristics of 800 aircraft in the area with 45 percent IPC-equipped and 5 percent ACARS-equipped.

7.2.3 Case 3 - Implementation of Hybrid Configuration of a Dedicated IPC VHF Data Link for Non-ACARS Members and IPC Using ACARS for ACARS Members

The Case 3 approach, as in the previous option, provides immediate IPC implementation to ACARS members (predominantly the commercial air carriers and selected high-performance general aviation) through use of the existing ACARS ground network and existing ACARS avionic equipment. The extension of IPC service to non-ACARS members in this option is provided by a dedicated IPC VHF data link similar to four options of Case 1.

The channel-capacity curves of Chapter Four indicate that the ACARS system operating within the system-design bit rate (2400 bps) can be satisfactorily augmented to handle IPC messages to ACARS members on a priority basis. The typical 1980s operating characteristics listed in Table 7-3 for IPC using ACARS are based on the aircraft density as derived from the 1982 Los Angeles Basin model with 5 percent of the 800 aircraft (i.e., 40 aircraft) both IPC- and ACARS-equipped. The channel utilization noted accounts for both the IPC and ACARS messages communicated over the channel, whereas the delay time refers to the uplink IPC delay time only. The maximum load capacity of an IPC/ACARS data link channel is dependent on possible increases in the percentage of ACARS-equipped aircraft as well as

Table 7-3. IMPLEMENTATION CASE 3 - HYBRID DEDICATED IPC AND IPC/ACARS VHF DATA LINK

System Concept	Equipment Parameter Set (See Table 4-6)	Typical 1980s Operating Characteristics (per channel)		Maximum Load Capability (Effective Number of Aircraft)	
		Utilization (Percent)	Delay Time (Seconds)	Per Channel	Per System (Total Hybrid System)
IPC Using ACARS	A	$\rho = 16$	$t = 0.60$	1050 aircraft with 13% IPC- and ACARS-Equipped (i.e., 137 aircraft)	-
Dedicated IPC Data Link					
One Way					
Single Channel	C	$\rho = 24$	$t = 0.39$	925*	985**
Four Channel	A	$13 \leq \rho < 33$	$0.56 \leq t < 0.98$	640*	1050†
	B	$11 \leq \rho < 28$	$0.40 \leq t < 0.62$	735*	1050†
One Way					
Single Channel	B	$\rho = 31$	$t = 0.61$	820*	830**
	C	$\rho = 17$	$t = 0.25$	1065*	1050†
Four Channel	A	$10 \leq \rho < 24$	$0.37 \leq t < 0.57$	780*	1050†

*Maximum effective number of aircraft allowable on the indicated dedicated IPC data link channel.

**Total effective aircraft level at which the communications workload for the dedicated data link channel surpasses the 70 percent utilization and/or 2-second uplink IPC delay time criteria.

†Effective number of aircraft represented is indicative of the fact that the total hybrid data link capacity is limited by IPC/ACARS data link.

increases in aircraft density. In the analysis it has been assumed that long-range IPC implementation with ACARS will approach 13 percent of the area population (contingent on all the high-performance general aircraft becoming ACARS users). For continuity in the tables, the maximum channel load capability is stated in terms of total aircraft, of which 13 percent are assumed to be IPC- and ACARS-equipped. The determined maximum level of aircraft being serviced by an ACARS data link (i.e., handling both the IPC and ACARS traffic) is constrained by requiring a total channel utilization of 70 percent or less and uplink IPC delay times no greater than 2 seconds. Table 7-3 indicates that the ACARS link can support a long-term workload generated by the assumed percentage of ACARS members (13 percent) if the total aircraft population does not exceed 1050.

The typical 1980s operating characteristics of the dedicated IPC data links are computed by assuming that 5 percent of the initial total communications workload will reside on the IPC/ACARS link. The reduced channel utilization is then calculated and correlated to a delay time. As in Section 7.2.1, it is assumed for evaluation of the four channel alternatives that between 30 percent and 75 percent of the remaining communications will reside on any one altitude-band frequency. For computing the maximum load capability, it is assumed that approximately 13 percent of the total IPC communications will be handled by the IPC/ACARS link and 87 percent will have to be served by the dedicated IPC link.

The maximum aircraft load per channel from Table 7-3 represents the maximum number of aircraft that can be handled by the channel without exceeding the 70 percent utilization or 2-second delay time requirements. The maximum aircraft load per system indicated in the table is the total effective number of aircraft generating communications that saturate either the dedicated or the ACARS data link. The capability of the hybrid concept depends on the level of IPC/ACARS usage and the operating characteristics of both the chosen dedicated data link and the IPC/ACARS link. These factors, in turn, are functions of the aircraft density and rate of conflict occurrence. Table 7-3 indicates that the duplex single-channel option (parameter set C) and the altitude-banding options of the dedicated IPC data links can be used with the IPC/ACARS link to configure hybrid systems with long-term capability.

7.3 CAPABILITY AND COST SUMMARY

The performance evaluation has shown that both interim and long-term service can be provided through use of various options of the proposed VHF data link concepts. A level of capability sufficient to provide service to initial users of an interim IPC data link was exhibited by certain options developed within the dedicated and hybrid IPC data link concepts. Table 7-4 summarizes the unit avionics costs as a function of interim and long-range capability for each system concept considered under the proposed IPC options. It indicates that interim to long-term IPC capability can be provided to commercial air carriers over a dedicated data link at a unit avionics cost of between $2,011 to $3,172 per aircraft, assuming single

Table 7-4. CAPABILITY AND COST SUMMARY OF THE IPC VHF DATA LINK CASES

Option	System Capability*		Unit Avionics Costs (Dollars)		
			Commercial and MAC	General Aviation	
	Interim	Long Term		High Performance	Low Performance
Dedicated Data Link					
1 - Single Channel, One Way	X	N/A	2011	2620	738
2 - Four Channel, One-Way	X	X	2233	2910	903
3 - Single Channel, Duplex	X	N/A	2885	3762	1047
4 - Four Channel, Duplex	X	X	3172	4135	1260
IPC/ACARS Data Link					
IPC Using ACARS	X	N/A	1207	1568	-
IPC Using Mini-ACARS		-	-	-	593*
Hybrid					
With Dedicated Option 1	X	N/A			
ACARS Users			1207	1568	-
Non-ACARS Users			-	-	738
With Dedicated Option 2	X	X			
ACARS Users			1207	1568	-
Non-ACARS Users			-	-	903
With Dedicated Option 3	X	X			
ACARS Users			1207	1568	-
Non-ACARS Users			-	-	1047
With Dedicated Option 4	X	X			
ACARS Users			1207	1568	-
Non-ACARS Users			-	-	1260

*Not including VHF transceiver

**X = capability exists; N/A = not applicable.

(nonredundant) system configurations. General aviation can be equipped for participation in a dedicated link at avionics costs ranging from $738 to $1,260 for low-performance aircraft and $2,620 to $4,135 for high-performance aircraft. The IPC/ACARS data link was shown to have only enough capability to sustain IPC levels of communications typical of near-term system use. The associated avionics costs for this service, presented in Table 7-4, are representative of the costs involved in modifying the ACARS avionics of commercial air carriers and high-performance general aviation and the avionics costs (excluding VHF transceiver) associated with the low-performance general aviation mini-ACARS. Typical avionics costs for long-term use of the hybrid option are summarized in the table as approximately $1,207 for commercial air carriers, $1,568 for high-performance general aviation, and $903 to $1,260 for low-performance general aviation (depending on the chosen dedicated data link option).

Judgments concerning which concept or concepts provide the most cost-effective interim and long-term VHF data link approach to collision avoidance would have to be based on more than the avionics costs developed. A cost-effectiveness assessment would include an extensive life-cycle-cost analysis of the avionics system, as well as a study of the support required for ground IPC VHF systems and interface systems.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

The study has shown that IPC can be implemented by using VHF data links with avionics of reasonable cost. Whether an IPC VHF data link should be considered seriously will depend on the cost and performance of alternative approaches and the integration of all FAA future plans and developments.

The study has focused on three potential VHF data link concepts and analyzed their use in an IPC separation-assurance system. The data links proposed for the analysis were a dedicated VHF data link for IPC traffic only, a combined company communications and IPC VHF data link, and a combined FAA/ATC tactical and IPC VHF data link. Since near-term implementation of an FAA/ATC tactical and IPC VHF data link was considered impractical, the concept was not evaluated in detail. The other two concepts, as well as a hybrid mixture of these two concepts, were evaluated for throughput capacity and avionics costs. The hybrid system configuration was based on the transmission of IPC commands on an ACARS data link for commercial air carriers (and potentially some high-performance general aviation aircraft) and on a dedicated VHF data link for the remainder of the aviation population.

The performance analysis of these IPC VHF data links was based on an analytical model of the data link channel-management characteristics. This analytical channel-capacity model incorporated the correlation between various aircraft densities and percentages of IPC system users and the resulting IPC communications workloads. The model was used in evaluating the impact of various modes of IPC VHF data link channel-management and data link characteristics of ground equipment and avionics to establish the data link system performance in terms of total channel utilizations and uplink IPC delay times.

Designs of equipment configurations required by each potential class of system users (air carriers, MAC aircraft, and both high- and low-performance general aviation) were developed for each IPC VHF data link concept analyzed. The avionics costs developed were based on these equipment designs and reflected the major cost factors of typical air carrier and general aviation avionics manufacturers.

8.1 NEAR-TERM FEASIBILITY OF USING A VHF DATA LINK IN AN IPC SEPARATION-ASSURANCE SYSTEM

The principal conclusion resulting from this analysis of proposed IPC VHF data links is that it is technically feasible to sustain near-term communications workloads of an IPC system implemented over a VHF data link. The characteristics of the possible VHF data links for this near-term IPC system were found to be well within the state of the art of avionics and obtainable with large percentages of currently used avionics and FAA ground equipment. The concept of a dedicated single-nationwide-channel data link for use by IPC exhibited sufficient capability to accommodate near-term traffic loads and expected levels of IPC system users. This dedicated data link could be configured as either a one-way system (one-frequency ground-air link) or a duplex system (a pair of frequencies: one ground-air, one air-ground) depending on the necessity for a reply to the uplink IPC command. Of the developed unit avionics costs for the dedicated IPC VHF data links, the lowest cost was associated with the single-channel one-way option because of the minimal avionics required for this option. The avionics costs of $2,011 for commercial air carriers, $2,620 for high-performance general aviation, and $738 for low-performance general aviation are representative of the minimal unit avionics costs expected under the implementation of a dedicated IPC VHF data link for near-term service.

The ACARS VHF data link network was also found capable of providing near-term IPC service. Implementation of this concept requires modification of system data rate and addition of IPC logic processing and display for ACARS-equipped aircraft. Avionics costs developed under this concept account for augmenting ACARS equipment of the commercial air carriers and high-performance general aviation ($1,207 and $1,568, respectively) and making new installations of mini-ACARS in low-performance general aviation aircraft at an avionics cost of $593 (excluding a VHF transceiver). Although economically more acceptable than the dedicated concepts, the IPC/ACARS system was found to be capacity-limited. Its operating characteristics are heavily dependent on both the number of ACARS users and the level of ACARS communications. In addition to the resolution of interface equipment and operating procedures, the FAA and ACARS users would have to reach an agreement concerning the use of the network by non-ACARS members.

8.2 LONG-TERM FEASIBILITY OF USING A VHF DATA LINK IN AN IPC SEPARATION-ASSURANCE SYSTEM

The analysis has indicated that certain IPC VHF system concepts offer sufficient capacity to service the expected long-term separation-assurance communications traffic load of the 1990s.

The IPC VHF dedicated data link could provide long-term capacity with the altitude-banding configurations of either the one-way or duplex options. The lower communications workload associated with each frequency in these options permits the use of equipment characteristics that are well within the state of the art and widely used by both air carrier and general aviation

aircraft. Avionics cost developments for this concept indicate required expenditures of $2,233 or #3,172 for commercial air carriers, $2,909 or $4,135 for high-performance general aviation, and $903 or $1,260 for low-performance general aviation (the lower cost associated with one-way altitude banding and the higher cost with duplex altitude banding).

The hybrid system configuration was found to provide long-term capability through combination of the ACARS data link with either an altitude-banded one-way dedicated VHF data link or a single-frequency duplex VHF data link. In the avionics cost developments for this system, it was assumed that air carrier and high-performance general aviation aircraft will modify their ACARS avionics at a cost of $1,207 and $1,568, respectively. The unit avionics costs to the low-performance general aviation users are based on the dedicated VHF data link concept; these costs are $903 or $1,047 depending on whether the dedicated link is configured as an altitude-banded one-way, or single-frequency duplex system.

8.3 FURTHER AREAS OF INVESTIGATION

This study demonstrates the technical feasibility of implementing IPC commands over a VHF data link. The capability exhibited and the avionics costs developed are only the first steps in determining the benefits, cost-effectiveness, and total commitment involved in implementing an IPC VHF data link program. This section identifies major technical and economic areas that must be analyzed further before the FAA proceeds with development of an IPC VHF data link.

8.3.1 Technical Investigations

This study has concentrated on the avionics complexity of an IPC VHF data link system. To account completely for all technical aspects of such a system, it is necessary to determine both the IPC ground facilities and nationwide altitude bands and overlap regions. The investigation of IPC ground facilities would include evaluation of the equipment and operations involved in each of the IPC VHF system concepts. Nationwide location of transmitter stations, areas of coverage, and correlation procedures for adjacent transmitters should be investigated. Ground systems necessary for interfacing with the ACARS network should be identified, and operational and technical concerns of the near-term IPC/ACARS or long-term hybrid IPC VHF system concepts should be resolved.

Long-term capability of the IPC VHF system has been shown to depend on the use of altitude banding of a dedicated VHF data link. Nationwide topology and traffic densities would have to be investigated to determine applicable nationwide altitude bands and overlap regions for the system concepts in which it is proposed to use this technique.

8.3.2 Economic Investigations

Upon the conclusion of the technical investigations, a life-cycle-cost analysis of the IPC VHF systems should be performed. The objective of this economic study would be to measure and quantify the technical and economic benefits of the system concepts to establish the most cost-effective technique.

APPENDIX A

CAPABILITY ANALYSIS OF AN IPC/ATC VHF DATA LINK

1. INTRODUCTION

This appendix considers the system concept of a shared, priority-ordered data link designed to carry IPC and some form of digitized ATC traffic. Completely digital ATC communications would include the ATC tactical messages relaying assigned heading, altitude, VHF voice frequency, and airspeed, and the longer multi-character, free-text format of ATC record messages. The implementation of such a data link in the period of interest to this study is not anticipated. This appendix formulates most of the characteristics of a complete ATC digital communications link to define a valid interim IPC/partial ATC digital data link. The channel-capacity analysis of Chapter Four is then performed on this interim IPC/ATC data link.

2. MESSAGE FORMATS

2.1 ATC Tactical Message Format

Reference 3 developed a message format and display for ATC tactical data. Figure A-1 and the discussion that follows are based on this work.

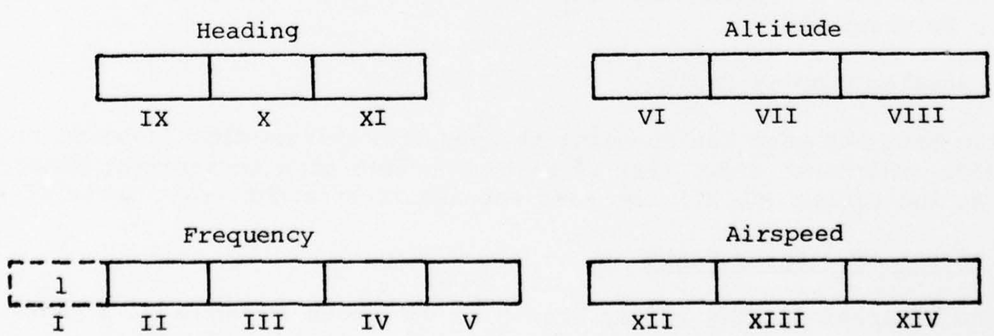


Figure A-1. ATC TACTICAL DISPLAY

2.1.1 VHF Frequency Display Field

The constraints imposed on the range of VHF frequencies available for aircraft use can be incorporated into the coding scheme to reduce unnecessary bit transmission. It is apparent that there are only four significant digits in the frequency range of 118.000 through 135.975 MHz when the range is considered in increments of 0.025 MHz (i.e., there are 720 channels).

The first digit (I) is always a "1" and can be permanently shown on the display face, whereas the sixth digit need not be displayed since it assumes the value 0 or 5, which is implied explicitly by the value of the fifth digit (V).

The second digit (II) assumes the values 1, 2, or 3, which can be coded in straight binary.

The third and fourth digits (III and IV) both can range from 0 through 9 and therefore should be encoded in BCD.

The fifth (V) digit can take on only the values 0, 2, 5, and 7. It can be encoded by two bits as follows:

00 = 0, 01 = 2, 10 = 5, and 11 = 7

It is thus implied that the number of bits necessary for VHF frequency determination is 12 bits. Although a more compact scheme using 10 bits would be possible, it was believed that the potential design simplifications would support the additional 2 bits.

2.1.2 Altitude Display Field

Altitude ranging from 0 to 79,000 feet in increments of 500 feet will be coded by use of 8 bits as follows: the first altitude digit (VI) ranging from 0 to 7 is encoded by the first 3 bits in BCD. The second digit (VII) ranges from 0 to 9 and will be encoded in straight 4-bit BCD. The third digit (VIII) has only two possible values, 0 to 5, and needs only 1 bit to be coded (i.e., "1" would cause the numeral 5 to be displayed, and "0" would cause 0 be displayed).

2.1.3 Heading Display Field

Ten bits are used for encoding the possible 360 headings ranging from 0 to 359. The first digit (IX) is encoded by two bits in straight binary. The next two digits (X, XI) are each encoded in straight 4-bit units of BCD.

2.1.4 Airspeed Display Field

The airspeed display ranges from 0 to 995 knots in units of 5 knots and is encoded by the use of 9 bits. The first two digits (XII, XIII) are encoded in straight BCD in two 4-bit groups. The last digit (XIV) can be coded with 1 bit by the use of the same technique mentioned for the third altitude digit.

2.1.5 Operation Determinant (OD) Field)

After each coding sequence, two bits are reserved for the following display management functions. A 00 code in this field commands that a blank be shown. A 01 code commands that the old content be replaced with the new and that the numerals be lighted continuously. A 10 code has the same meaning as 01, with the additional command that the numerals be flashed. A 11 code overrides any present content of the transmitted field and directs the display to remain as is.

Figure A-2 shows the bit assignments for the total 47-bit text of ATC tactical transmissions.

VHF	OD	Altitude	OD	Heading	OD	Airspeed	OD
12 bits	2	8	2	10	2	9	2

Figure A-2. TEXT FORMAT FOR ATC TACTICAL MESSAGE

2.2 ATC RECORD MESSAGE FORMAT

ATC record communications, composed of such non-time-critical messages as flight plan revisions, weather reports, and ATIS reports, will have the characters of their text coded in a manner similar to the ACARS message format described in Chapter Three (Section 3.1.2) of this report. This implies that the message format of a complete digital ATC and IPC VHF data link will have the following message structure:

Function	Length
Pre-Key	16 characters
Bit Synchronization	2 characters
Character Synchronization	2 characters
Start of Heading	1 character
Mode	1 character
Address	7 characters
Technical Acknowledgment	1 character
Label	2 characters
Start of Text	1 character
Text	
ATC Tactical Text	6 characters (47 + 1 bits)
ATC Record Text	220 characters (maximum)
IPC Text	2 characters (13 + 3 bits)
Suffix	1 character
BCS	16 bits
BCS Suffix	1 character

3. MESSAGE-ARRIVAL RATES

The message arrival rates of ATC communications are a function of flight rules (IFR, VFR) and airspace in which an aircraft is operating (TCA, en route, etc.).

3.1 ATC Tactical Uplink Message-Arrival Rates

The following message-arrival rates have been generated for ATC tactical message traffic (see Reference 11 for further details).

3.1.1 Message-Arrival Rates for IFR Aircraft in the TCA and En Route Areas

Representative message types and frequency of occurrence of such communications for IFR aircraft arriving or departing in a TCA are given in Table A-1.

Table A-1. ATC TACTICAL COMMUNICATIONS FOR TERMINAL CONTROL AREA IFR AIRCRAFT

Message Type	Number of Messages per Aircraft		Number of Minutes under Control	Number of Messages per Aircraft per Minute	
	Arrival	Departure		Arrival	Departure
Altitude Assignment	4	2	20	0.20	0.10
Heading Assignment	6	2	20	0.30	0.10
Speed Assignment	4	2	20	0.20	0.10
Voice Frequency Assignment	2	2	20	0.10	0.10
Total				0.80	0.40

If equal numbers of arrivals and departures are assumed, then the mean rate of 0.60 message per aircraft per minute is used.

For aircraft in en route areas (i.e., above 10,000' MSL) an overall maximum average of 0.26 message per aircraft per minute is assumed.

3.1.2 Message Arrival Rates for VFR Aircraft in TCA and VFR Highway

Table A-2 indicates typical message types and frequency of occurrence of ATC Tactical Communications for VFR aircraft in either the TCA or VFR Highway.

Table A-2. ATC TACTICAL COMMUNICATIONS FOR TERMINAL CONTROL AREA VFR AIRCRAFT

Message Type	Number of Messages per Area per Aircraft	Number of Minutes under Control or within Area	Average Number of Messages per Aircraft per Minute
Altitude Assignment	1 per flight	20	0.05
Heading Assignment	2 per flight	20	0.10
Speed Assignment	1 per flight	20	0.05
Voice Frequency Assignment	1 per flight	20	0.05
Total			0.25

3.1.3 Message-Arrival Rates for IFR and VFR Aircraft in Mixed *Airspace*

It is assumed that all applicable IFR aircraft in mixed airspace will receive ATC tactical messages at the same rate as IFR aircraft en route, and that 15 percent of the VFR aircraft in this area will receive at a rate approximately equal to that of VFR aircraft in TCA and VFR Highway areas. This implies that 15 percent of VFR and all applicable IFR aircraft will receive ATC tactical messages at a rate approximately equal to 0.26 message per minute.

3.2 ATC Tactical Downlink Message-Arrival Rates

In this appendix it is assumed that all uplink messages to an aircraft will be verified as to their content by either an automatic technical acknowledgment (ACK/NAK) or the pilot's acknowlegment and intent to comply (WILCO/UNABLE). The downlink transmission will contain the entire uplink message and appropriate acknowledgment. Whether this process is automatically handled without human intervention (as in the ACK/NAK case) or initiated only after receipt of the pilot's input (WILCO/UNABLE) is an operational concern. What results in either case is a downlink message-arrival rate equal to the uplink rate.

3.3 ATC Record Message-Arrival Rates

Only commercial carriers and high-performance general aviation are expected to implement the capability, typical of ATC record messages, for long, unformatted, free-text, and multi-alphanumeric-character transmissions over a digital link. Table A-3 lists the expected message types, character text lengths, and message frequency characteristics of ATC record communications for a one-hour flight.

Table A-3. ATC RECORD TRAFFIC CHARACTERISTICS				
Message Type	Uplink or Downlink	Typical one-hour Flight		
		Messages Flight per	Text Characters per Message	Characters per Flight
Flight Plan Revision	D	0.2	100	20
Noncontrol Advisory (ATIS)	U	1.0	300	300
Ground-to-Air Weather (En Route)	U	1.0	250	250
Ground-to-Air Weather (Terminal)	U	1.0	125	125
Terminal Update (ATIS)	U	1.0	50	50

Approximations drawn from Table A-3 are an ATC record message-arrival rate of 0.07 message per aircraft per minute and an average message test length of 175 characters.

4. PARTIAL ATC DIGITAL IMPLEMENTATION OPTION

Since total conversion to digital ATC operations is not attainable within the period of interest, the IPC/ATC VHF communications system concept is based on the near-term completion of a partial ATC data link. It is assumed that ATC tactical data have been digitized and implemented in the format discussed, with the eventual goal of including ATC record. Recipients of ATC tactical and IPC digital traffic will consist of the following aviation populations:

- All commercial aviation air carriers
- All MAC aircraft
- All general aviation aircraft in a Group I TCA
- 15% of all remaining general aviation aircraft

This distribution is equivalent to that shown in Chapter Four (Table 4-3) for IPC avionics capability.

5. IPC USING AN ATC TACTICAL VHF DATA LINK

The priority ordering, message lengths, and arrival rates of traffic on the IPC/ATC tactical data link are summarized in Table A-4. The current

ATC system operates on VHF frequencies distributed on the basis of geographical location and current aircraft flight status. The implementation of digital communications would tend either toward initiating a number of frequencies, each handling large geographic segments of the national airspace, or toward maintaining separate frequencies for control of aircraft in various flight operations, e.g., terminal or en route areas. Table A-4 exemplifies these possibilities by identifying two message-arrival rates for ATC tactical communications that are dependent on flight status.

Table A-4. IPC/ATC TACTICAL DATA LINK VARIABLES

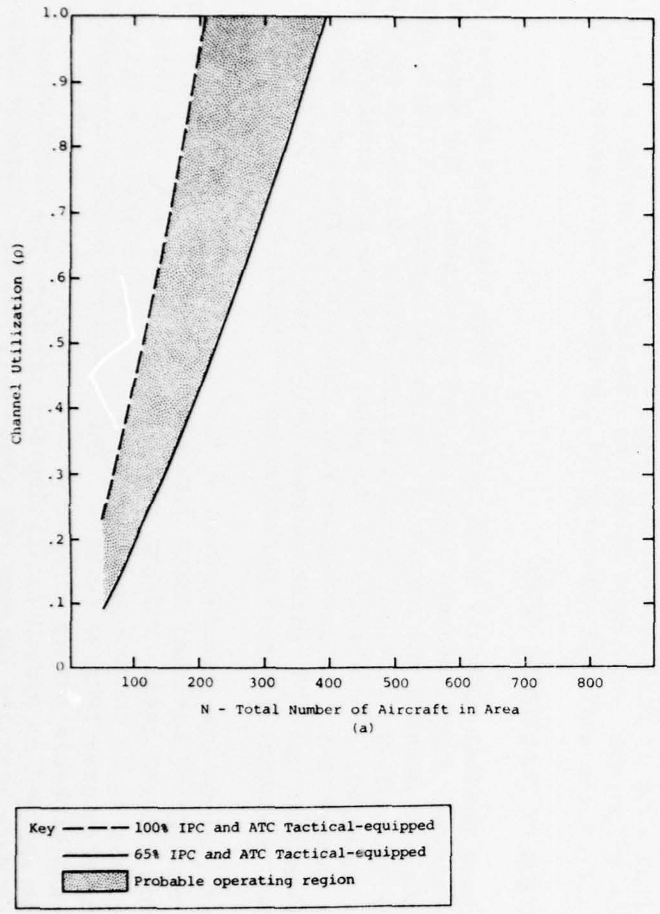
Message Type	Priority	Message Length (Bits)	Mean Arrival Rate (Messages per Aircraft per Minute
Uplink IPC	1 (highest)	184	See Figure 4-3 in Chapter Four
Uplink ATC Tactical	2	216	0.60 0.40
Downlink IPC	3	184	Equivalent to uplink rate
Downlink ATC Tactical	4 (lowest)	168-216	0.60 0.40

The mean arrival rate of 0.60 corresponds to the high rate of communications traffic found in terminal areas. This message rate will be used in conjunction with an equipment factor of 1 to simulate the maximum conversion to digital IPC and ATC communications within an area. The ATC tactical-message-arrival rate of 0.40 message per aircraft per minute will be associated with the 65 percent equipment factor to simulate the probable avionics sophistication of the aviation community of the entire Los Angeles Basin.

6. APPLICATION OF ANALYTICAL MODEL

The system channel-capacity model was used with Table A-4 as input for the message-arrival rates, message lengths, and priorities. The model was exercised twice to measure the impact of having 100 percent of the aircraft equipped for IPC and ATC tactical communications versus 65 percent of the aircraft so equipped. The results of the model exercise are exhibited in Figures A-3 through A-5. As in Chapter Four, the graphs represent total channel utilization and IPC uplink channel delay time (for 99 percent of the generated messages) for each parameter set of Table 4-5.

A brief qualitative investigation of the figures shows the impracticality of the concept of handling large segments of airspace by a single VHF frequency for IPC/ATC data. Further analysis beyond the scope of this study would have to be conducted to determine the capability of a flight-status multi-frequency IPC/ATC network. This analysis would concentrate on current and probable future procedures for flight-status handling, the requirements imposed on ground facilities for tracking and correlating surveillance data with the appropriate frequency, and the probable maximum aircraft densities that a frequency should be capable of handling.



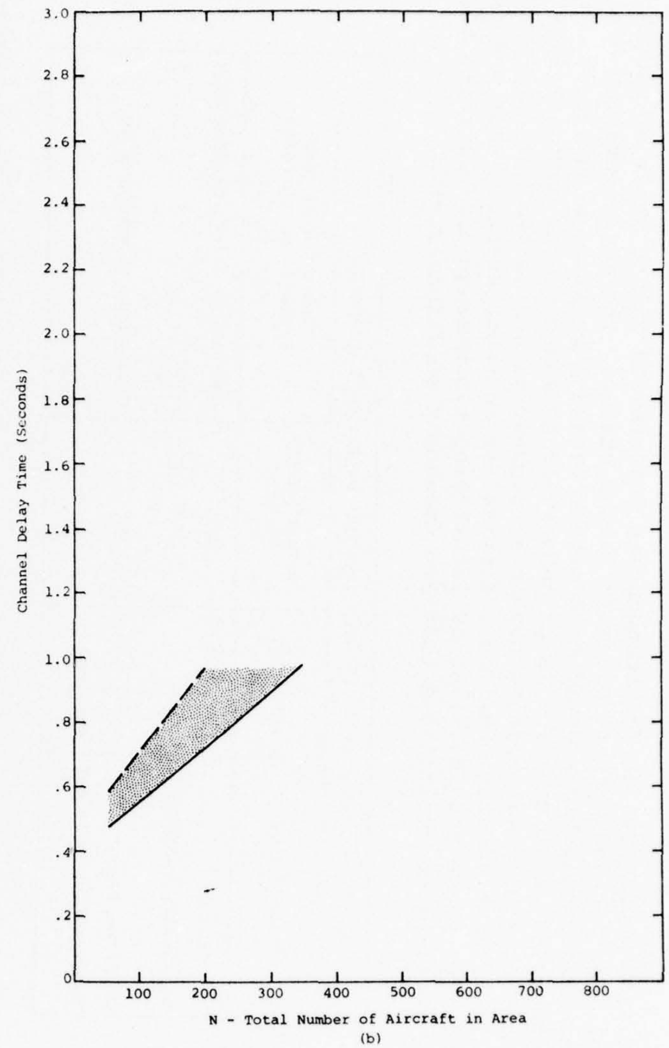


Figure A-3. CHANNEL UTILIZATION AND DELAY OF IPC/ATC TACTICAL DATA LINK (PARAMETER SET A)

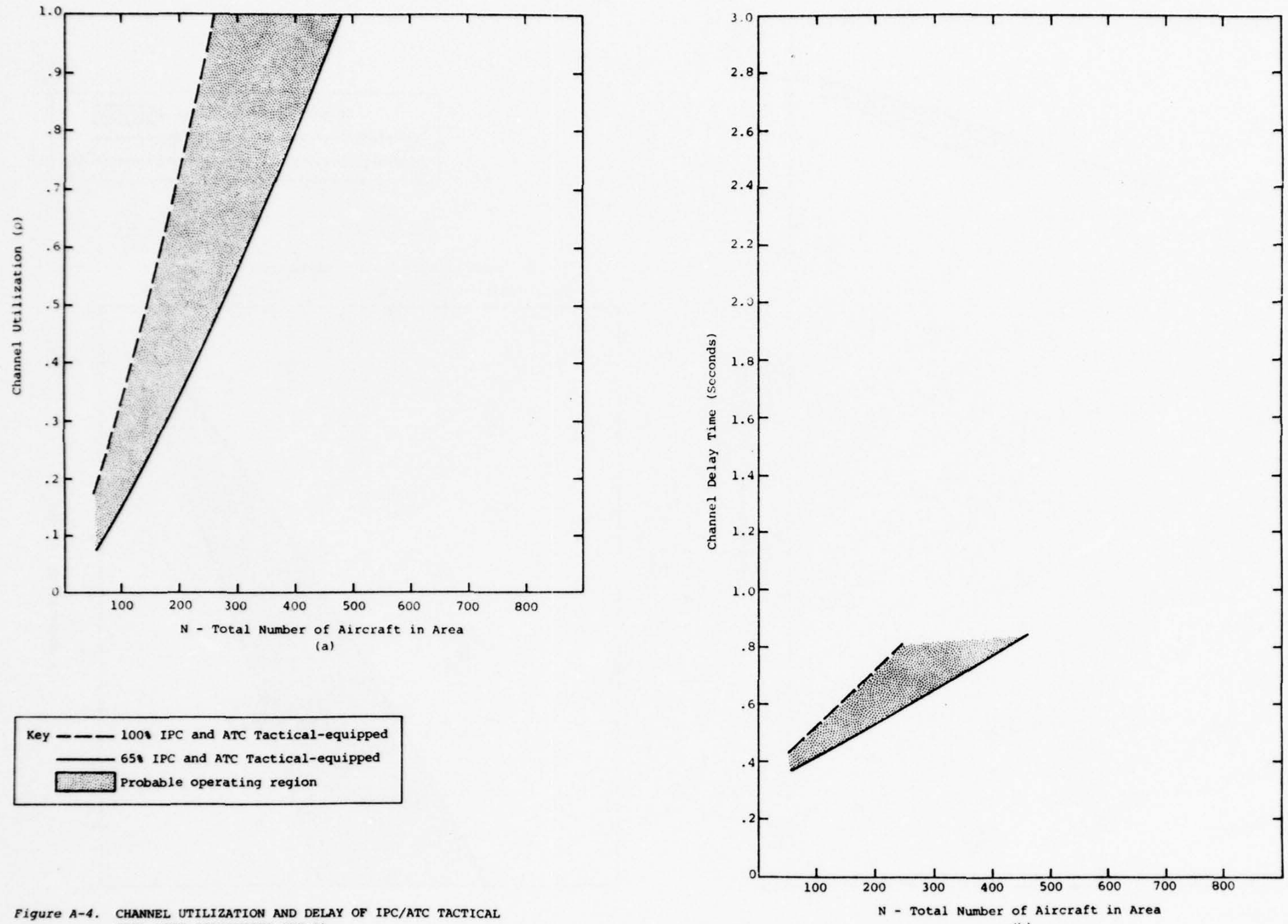


Figure A-4. CHANNEL UTILIZATION AND DELAY OF IPC/ATC TACTICAL DATA LINK (PARAMETER SET B)

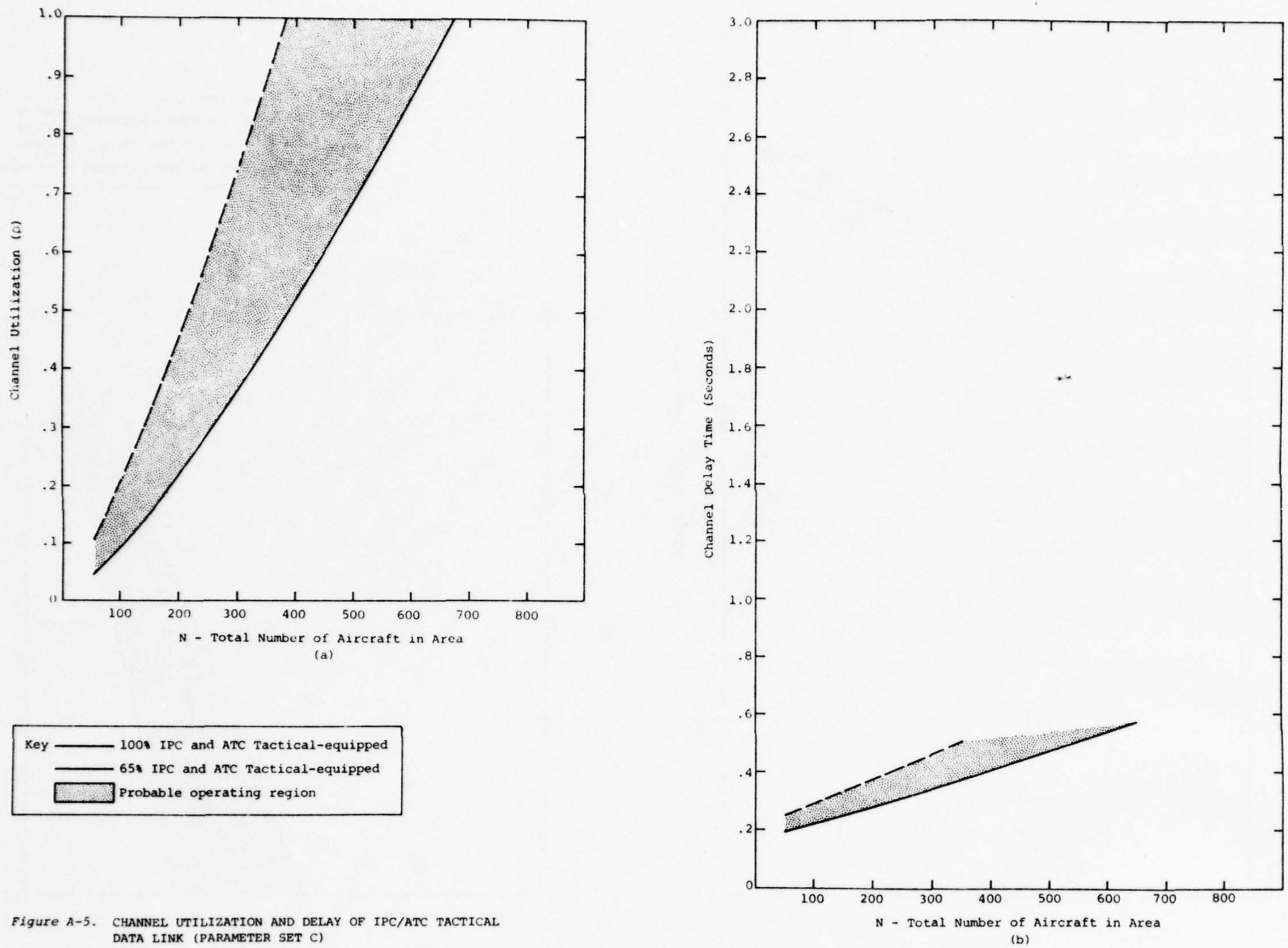


Figure A-5. CHANNEL UTILIZATION AND DELAY OF IPC/ATC TACTICAL DATA LINK (PARAMETER SET C)

APPENDIX B

SYSTEM CHANNEL-CAPACITY MODEL

The system channel capacity of an IPC VHF data link is a function of many variables. This appendix identifies the predominant factors and incorporates them in a model of IPC VHF data link operations.

The following variables are considered:

N - total number of aircraft in the area

j - a set of values representing the priority and type of message traffic on the data link (j=1 is the highest-priority message class)

E(j) - mean arrival rate of message type j per aircraft

L(j) - number of bits in message type j

R - bit rate

The number and identity of priority levels for the variable j are determined uniquely when a specific data link concept is being considered. The following table provides the transformation of message type to numeric for use by the proposed data links:

Priority	IPC Dedicated	IPC/ACARS	IPC/ATC
j=1	Uplink IPC	Uplink IPC	Uplink IPC
j=2	(Downlink IPC)	Uplink ACARS Acknowledgment	Uplink ATC Tactical
j=3	-	Downlink IPC	Uplink ATC Record
j=4	-	Downlink ACARS	Downlink IPC
j=5	-	-	Downlink ATC Tactical
j=6	-	-	Downlink ATC Record

Table 4-3 of Chapter Four indicates that not all aircraft in a given area will be utilizing all the possible VHF data link communications capabilities. To calculate the total number of aircraft equipped for message type j traffic, it is assumed that the percentage of aircraft equipped is a constant as the total number of aircraft, N, varies.

With IPC traffic, the concern is not the number of aircraft equipped for IPC but, given a conflict situation between two aircraft, the probability that one or both of the aircraft will be equipped for IPC traffic, and the message-generation rate for such situations. The use of a hypergeometric distribution with N as the total aircraft population, D the number of aircraft equipped for IPC, and a random sample of n=2 aircraft, results in the following probability of having one or both aircraft IPC-equipped:

$$p(1) + p(2) = \sum_{x=1}^{2} \frac{\binom{D}{x}\binom{N-D}{n-x}}{\binom{N}{n}} = \frac{D[2N - D - 1]}{N^2 - N} \text{ (for } n = 2)$$

The result of this equation is the probability of resolving a conflict situation between two aircraft. What is needed now is the quantity of communications involved in situations where fewer than 100 percent of the aircraft are IPC-equipped. Assuming two commands per aircraft per conflict, the quantity of IPC communications is calculated as follows:

If

$p(1)$ = probability of one aircraft being IPC-equipped out of two in conflict (calculated from the hypergeometric distribution)

$p(2)$ = probability of both aircraft in conflict being IPC-equipped (by use of hypergeometric distribution)

C = number of conflicts per minute per aircraft

then the average total channel message-arrival rate for IPC commands, $A(1)$, can be computed by accounting for two commands when only one aircraft is equipped or four commands when both are equipped, i.e.,

$$A(1) = [4p(2) + 2p(1)]\ CN$$

Figure 4-3 of Chapter Four provides a mean arrival rate of IPC commands given that all aircraft are IPC-equipped. This arrival rate, $E(1)$, is related to the conflict rate, C, by the equation

$$E(1) = 4C \text{ or, equivalently, } C = E(1)/4$$

Substituting for C in terms of $E(1)$ in the equation for $A(1)$ yields

$$A(1) = \left(p(2) + \frac{p(1)}{2}\right) E(1)N$$

Therefore, the factor that relates the level of IPC-equipped aircraft to the quantity of IPC communications is

$$\left(p(2) + \frac{p(1)}{2}\right)$$

Factors regulating the number of j type communications being generated for various levels of avionics capability and total number of area aircraft are represented by the variable N(j). The following table indicates the values of N(j) as determined by the avionics capability and distribution of traffic described in Section 4.1 of Chapter Four.

Equipped Aircraft as a Percentage of Total Population	Communications Factor, N(j)
IPC	
100	N(1) = 1.000
65	N(1) = 0.649
45	N(1) = 0.457
13	N(1) = 0.129
5	N(2) = 0.047
ACARS	
13 (maximum)	N(2) = N(4) = 0.130
5 (minimum)	N(2) = N(4) = 0.050

It is now possible to calculate the parameters of class j traffic on the channel as follows:

$$A(j) = N\ N(j)\ E(j), \text{ mean message-arrival rate for the channel}$$

and

$$t(j) = L(j)/R, \text{ mean transmission time}$$

This implies that the total channel mean message-arrival rate is given by

$$A = \sum_{j=1}^{m} A(j)$$

where m equals the numeric equivalent of the lowest-priority message type for the scenario being analyzed. Inherent in the VHF data link are propagation and processing-time delays. Propagation delays are assumed to be small enough to be neglected. Processing times are functions of the equipment and are analyzed from the viewpoints of the avionics and ground facilities. Avionic equipment is influenced by the carrier rise time (CRT) of the ground transmitter and the automatic gain control (AGC) settling time of the aircraft receiver. This processing or delay time affects the uplink message service time and is identified by the variable d_A. Downlink message delays

are caused by carrier rise time of the avionic equipment and ground receiver AGC settling time; this processing time is identified by the variable d_G. Section 3.5 of Chapter Three provides the equipment characteristics for calculating these delay times for the spectrum of existing equipments.

Equipment Characteristics	Delays of Equipment		
	Ground (ms)	Avionics (ms)	Total (Seconds)
Low Performance			
Ground to Air	CRT 50	AGC 100	$d_A = 0.15$
Air to Ground	AGC 50	CRT 50	$d_G = 0.1$
High Performance			
Ground to Air	CRT 25	AGC 50	$d_A = 0.08$
Air to Ground	AGC 25	CRT 25	$d_G = 0.05$

Processing times in the equations to be developed will be represented by the step function p(j) defined to have the following properties:

$$p(j) = \begin{cases} d_A & \text{for } j = \text{uplink message} \\ d_G & \text{for } j = \text{downlink message} \end{cases}$$

$E\left(ts_j\right)$, the mean service time for message type j, is defined as the sum of transmitting time, t(j), and processing time, p(j), which results in the mean service time of the system

$$E(t_s) = \sum_{j=1}^{m} \frac{A(j)}{A} \; E\left(ts_j\right)$$

From these two results, the fractional channel utilization due to priority j messages and the total channel utilization are calculated as:

$$\rho_j = A(j)\; E\left(ts_j\right) \tag{1a}$$

and

$$\rho = \sum_{j=1}^{m} \rho_j \tag{1b}$$

Standard priority queueing theory techniques (References 12 and 13) result in the following expressions:

The mean waiting time for priority n messages is

$$E\left(t_{w_n}\right) = A\ E\left(t_s{}^2\right) \Big/ \left(2\left[1 - \left(\rho_1 + \rho_2 + --- + \rho_{n-1}\right)\right] \times \left[1 - \left(\rho_1 + \rho_2 + --- + \rho_n\right)\right]\right) \tag{2}$$

The mean number of priority n messages waiting is

$$E(w_n) = A(n)\ E\left(t_{w_n}\right) \text{ or, equivalently,}$$

$$E(w_n) = A\ A(n)\ E\left(t_s{}^2\right) \Big/ \left(2\left[1 - \left(\rho_1 + \rho_2 + --- + \rho_{n-1}\right)\right] \times \left[1 - \left(\rho_1 + \rho_2 + --- + \rho_n\right)\right]\right) \tag{3a}$$

The mean time an item spends in the system waiting and being served is

$$E\left(t_{q_j}\right) = E\left(t_{w_j}\right) + E\left(t_{s_j}\right) \tag{3b}$$

The second moment of waiting time for priority n messages is

$$\begin{aligned} E\left(t_{w_n}{}^2\right) = {} & A\ E\left(t_s{}^3\right) \Big/ \left(3\left[1 - \left(\rho_1 + \rho_2 + \ldots + \rho_{n-1}\right)\right]^2 \times \left[1 - \left(\rho_1 + --- + \rho_n\right)\right]\right) + A\ E\left(t_s{}^2\right) \left[A(1)\ E\left(t_{s_1}{}^2\right)\right. \\ & \left. + A(2)\ E\left(t_{s_2}{}^2\right) + --- + A(n)\ E\left(t_{s_n}{}^2\right)\right] \\ & \div \left(2\left[1 - \left(\rho_1 + \rho_2 + --- + \rho_{n-1}\right)\right]^2 \left[1 - \left(\rho_1 + --- + \rho_n\right)\right]^2\right) \\ & + A\ E\left(t_s{}^2\right) \left[A(1)\ E\left(t_{s_1}{}^2\right) + A(2)\ E\left(t_{s_2}{}^2\right)\right. \\ & \left. + --- + A(n-1)\ E\left(t^2{}_{s_{n-1}}\right)\right] \div \left(2\left[1 - \left(\rho_1 + --- + \rho_{n-1}\right)\right]^3 \right. \\ & \left. \times \left[1 - \left(\rho_1 + \rho_2 + --- + \rho_n\right)\right]\right) \end{aligned} \tag{4}$$

The second moment of the overall waiting time is then given by

$$E\left(t_w{}^2\right) = \frac{A(1)}{A}\ E\left(t^2{}_{w_1}\right) + \frac{A(2)}{A}\ E\left(t^2{}_{w_2}\right) + --- + \frac{A(m)}{A}\ E\left(t^2{}_{w_m}\right)$$

From these second moments and means, the standard deviation of waiting time for each priority message type can be expressed as

$$\sigma t_{w_j} = \left[E\left(t^2{}_{w_j}\right) - E^2\left(t_{w_j}\right) \right]^{1/2} \tag{5}$$

Equations 2 through 5 are greatly simplified by the reasonable assumption of exponential service times, implying

$$E\left(t^2{}_s\right) = 2E^2\left(t_s\right) \text{ and } E\left(t^3{}_s\right) = 6E^3\left(t_s\right)$$

The time responsiveness of the data link can be indicated by exhibiting the time necessary to ensure the delivery of IPC messages within a certain probability level. Qualitative examinations support the use of a normal distribution as an upper bound in deriving the probable elapsed time of ensuring (with .99 probability) that IPC messages have been serviced (transmitted and received).

The normal distribution is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \, e^{-(x - \mu)^2/2\sigma^2} \quad \text{where } -\infty < x < \infty$$

implying

$$P(x \leq X) = F(X) = \int_{-\infty}^{X} f(x)dx$$

Given that $P(x \leq X)$ must equal .99, then to find the value of X that satisfies this for all μ and σ of the output, it is necessary to use the standard normal distribution. The transformation of variable x to Z, the standard normal distribution variable, is

$$Z = \frac{x - \mu}{\sigma}$$

implying

$$f(Z) = \frac{1}{\sqrt{2\pi}} \, e^{-Z^2/2}$$

and

$$\int_{-\infty}^{\infty} f(Z)dz = F(Z) = P(z \leq Z) = .99 \tag{6}$$

By use of standard normal distribution tables, the value of Z for which Equation 6 is satisfied is 2.33. It is now possible to substitute into the standard normal distribution transformation and solve for x, the total channel delay time. This results in the equation

$$60\ (2.33\sigma + \mu) = x \text{ seconds}$$

where

σ = standard deviation of waiting time, Equation 5

μ = total time waiting and being served, Equation 3b

Tables B-1 and B-2 summarize the parameter values and the input data for the channel-capacity computer model. Figure B-1 is the computer listing of the model developed.

Table B-1. VARIABLES AND PARAMETER VALUES FOR THE CHANNEL-CAPACITY MODEL

Message Type	Message Bit Lengths	
	Short Format (+42 Overhead Bits)	Long Format (+168 Overhead Bits)
Uplink		
IPC	13	16
ATC Tactical	N/A	48
ATC Record	N/A	1546 (maximum 220 characters)
Company	N/A	712 (average test)
Tecnical Acknowledgment	0	0
Downlink		
IPC (Retransmission)	13	16
ATC Tactical	N/A	8-48
ATC Record	N/A	1540 (maximum)
Company	N/A	712 (average test)
Technical Acknowledgment	0	0

Equipment Characteristics

Parameter Set A

Bit Rate, R, = 2400 bps (144,000 bpm)

Delay Times: d_A = 0.15 second (0.0025 minute)
d_G = 0.10 second (0.0016 minute)

Parameter Set B

Bit Rate, R, = 4800 bps (288,000 bpm)

Delay Times: d_A = 0.15 second
d_G = 0.10 second

Parameter Set C

Bit Rate, R, = 4800 bps

Delay Times: d_A = 0.08 second (0.0013 minute)
d_G = 0.05 second (0.0008 minute)

Table B-2. COMPUTER MODEL INPUT DATA

Data Link Concepts	Computer Variables: NMAX	NUP	XNAC N(j)	Message Length (Bits)	EU	ED	IPC Response	Remarks
IPC Dedicated								The 205-bit message length reflects the fact that each IPC transmission is composed of three identical series of IPC command, overhead bits, and prekey. N(j) factors correspond to 100%, 65%, and 45% of the Los Angeles Basin aircraft being IPC-equipped, respectively.
One-Way Data Link	1	1	.457	205	-	-	No	
Repetitive Message	1	1	1.	205 (3×55 + 2×20)	-	-	No	
Short Message Format	1	1	.649	205	-	-	No	
IPC Dedicated								Represents uplink channel of a two-channel duplex link. N(j) factors are as stated above.
Two-Way Data Link	1	1	1.	55	-	-	No	
No Repetitive Message	1	1	.457	55	-	-	No	
Short Format	1	1	.649	55	-	-	No	
IPC/ACARS								
Uplink Acknowledgment to ACARS Message	4	2	1.,.13 1.,.13	184,168 184,880	.19	.19	Yes	Represents 100% IPC-equipped, 13% ACARS-equipped.
Long Format	4	2	.457,.05 .457,.05	184,168 184,880	.19	.19	Yes	Represents 45% IPC-equipped, 5% ACARS-equipped.
IPC Response	4	2	.047,.05 .047,.05	184,168 184,880	.19	.19	Yes	Represents input data for implementation option 3. A minimum of 5% ACARS- and IPC-equipped to a maximum of 13% ACARS- and IPC-equipped, respectively.
All Uplink and Downlink Traffic on Same Channel	4	2	.129,.13 .129,.13	184,168 184,880	.19	.19	Yes	

```
 77/07/15. 07.23.43.
PROGRAM   IPV

X
PROGRAM VHF(INPUT,OUTPUT)
DIMENSION E(12), A(12), R(4), DG(4), RHO(12), T(12),
+P(12), ET(12), XNAC(12), XLEN(12),DA(4)
1 PRINT, * NMAX, NUP*,
READ, NMAX,NUP
PRINT, *XNAC *,
READ, ( XNAC(I),I=1,NMAX)
PRINT, * LENGTH *,
READ, (XLEN(I),I=1,NMAX)
IF(NUP.EQ.1)GOTO 169
PRINT, *EU *,
READ, (E(I),I=2,NUP)
169 NDUM=NUP+2
IF(NDUM.GT.NMAX)GOTO 23
PRINT, *ED*,
READ,(E(I),I=NDUM,NMAX)
DATA (DA(I),I=1,3)/.0025,.0025,.0013/
DATA (DG(I),I=1,3)/.0016,.0016,.0008/
DATA (R(I),I=1,3)/144000.,288000.,288000./
23 PRINT,* RESPONSE *,
READ, AA
     XMR1=.0004
DO 2 I=1,3
PRINT,*R = *,R(I),* DA = *,DA(I),* DG = *,DG(I)
     DO 3 J=1,18  $NAC=50*J
PRINT,*NAC = *,NAC
     E(1)=NAC*XMR1
     E(NUP+1)=E(1)
IF (AA.NE.3HYES) E(NUP+1)=0.
ASUM=ROSUM=0.
DO 5 L=1,NMAX
A(L)=NAC*XNAC(L)*E(L)
T(L)=XLEN(L)/R(I)
XDUM=DA(I)
IF (L.GT.NUP)XDUM=DG(I)
P(L)=XDUM
ET(L)=T(L)+P(L)
RHO(L)=A(L)*ET(L)$ROSUM=ROSUM+RHO(L)
5 ASUM=ASUM+A(L)
IF(ROSUM .GT. 1.)GOTO 22
ETSUM=ROSUM/ASUM
PRINT,* TOTAL FACILITY UTILIZATION = *,ROSUM
PRINT 176
 176 FORMAT (7HMESSAGE,2X,11HUTILIZATION,2X,9HMEAN WAIT,2X,
+7HMEAN NO,2X,8HTOT TIME,2X,7HSTD DEV,2X,6HCH DEL)
DO 6 L=1,NMAX
XDUM=WDUM=0
DO 7 II=1,L
WDUM=WDUM+A(II)*ET(II)*ET(II)
7 XDUM=XDUM+RHO(II)
SDUM=WDUM-A(L)*ET(L)*ET(L)
YDUM=XDUM-RHO(L)
ZDUM=(1-YDUM)*(1-XDUM)
ETW=ASUM*ETSUM*ETSUM/ZDUM
ETM=A(L)*ETW
ETO=ETW+ET(L)
ETWS=2*ASUM*ETSUM*ETSUM*ETSUM/(ZDUM*(1-YDUM))
ETWS=ETWS+2*ASUM*ETSUM*ETSUM*WDUM/(ZDUM*ZDUM)
ETWS=ETWS+2*ASUM*ETSUM*ETSUM*SDUM/(ZDUM*(1-YDUM)*(1-YDUM))
STD=SQRT(ETWS-ETW*ETW)
    CDT=60*((2.33*STD)+ETO)
  6  PRINT 100,L,RHO(L),ETW,ETM,ETO,STD,CDT
 100 FORMAT(5X,I3,7X,F6.4,3X,F8.4,1X,F8.4,2X,F8.4,1X,F8.4,1X,F8.4)
22 CONTINUE
3 CONTINUE
2 CONTINUE
PRINT, *ANOTHER CASE*,
READ, AB
IF(AB.EQ.3HYES)GOTO1
STOP
END
009306
READY.
```

Figure B-1. COMPUTER LISTING OF CHANNEL-CAPACITY MODEL

APPENDIX C

METHODOLOGY FOR APPROXIMATING CHANNEL UTILIZATIONS AND DELAY TIMES FOR ALTITUDE-BANDED IPC FREQUENCIES

This appendix describes the methodology for approximating the improvement in system channel capacity due to assignments of VHF frequencies to various serial flight levels. Precise capacity calculations of these channels would involve determining discrete altitude bands, amount of overlapping coverage, and expected nationwide and local aircraft densities, in addition to calculating the rate of generation of conflict situations. Since such effort is not pertinent to the objectives of the contract, an approach was developed for approximating the reduction in channel utilization and delay times. The major assumption involved in this methodology is that it is possible to represent the communications load involved in an altitude band from the available data representing the total Los Angeles Basin.

For a given aircraft population, the total number of conflict situations in an area will remain constant regardless of whether the IPC commands are transmitted over a one-frequency system or a system comprising a set of altitude-banded frequencies. Therefore, in the implementation of an altitude-banded-frequency system, it will be necessary to optimize the system to deal with the following two constraints:

1. *Minimizing the channel utilization and delay times of each frequency*
2. Determining altitude bands that are realistic for national use

The first constraint is satisfied by having each of the four frequencies handle a maximum of 30 percent of the total IPC communications traffic -- 25 percent of the conflict-resolution communications plus an additional 5 percent of redundant communications due to overlap in coverage. This division of workload is obtained by a nonuniform allocation of MSL flight levels to the four frequencies. In many cases the resulting flight-level allocation will yield a division of the low altitudes into a set of narrow altitude bands. The total coverage (above MSL) of these low-altitude frequencies will be very limited because of topology. The strict minimization of communications load, then, does not satisfy the second constraint at low altitudes. To satisfy both constraints in this area, it is necessary to raise the percentage of communications load allocated to a frequency. A maximum communications load of 75 percent is proposed for low-altitude bands.

The bounds of 30 percent and 75 percent of the total communications load can easily be located on the channel-utilization curves of Chapter Four, Section 4.5, by the equations

$$30\% \text{ traffic load} = 0.30\rho_{100\%}(800)$$

$$75\% \text{ traffic load} = 0.75\rho_{100\%}(800)$$

where $\rho_{100\%}(800)$ represents the channel utilization of 800 aircraft all IPC-equipped. These points are located below the $\rho_{100\%}$ curve and on the line N=800. To arrive at approximate channel delay times, it is necessary to correlate the 30 percent and 75 percent utilization points to an "effective number of aircraft". This is done by projecting the 30 percent and 75 percent utilization points horizontally until they intersect the $\rho_{100\%}$ curve, and then determining the "effective number of aircraft" by projecting these points vertically to the horizontal axis. It should be noted that the "effective number of aircraft" figures do not necessarily equal the number of aircraft in the channel. The "effective numbers of aircraft" are used to locate an approximate expected-delay-time range of operation. This process is indicated on Figure C-1, a reproduction of Figure 4-4 from Chapter Four. It shows that altitude banding will result in probable operating regions of $30 \le \rho \le 0.75$ for channel utilization and $0.90 \le \rho < 3$ seconds for channel delay times. These maximum operating regions still violate the desired communications characteristics of Section 4.4.

This method of approximating utilization and delay times for the altitude-banding concept can be used to show that the equipment and data link characteristics represented by Figures 4-5 and 4-7 are adequate to provide IPC service within desired communications system operation. Figures C-2 and C-3 indicate the probable operating regions of the one-way and duplex dedicated IPC link for parameter sets B and A, respectively.

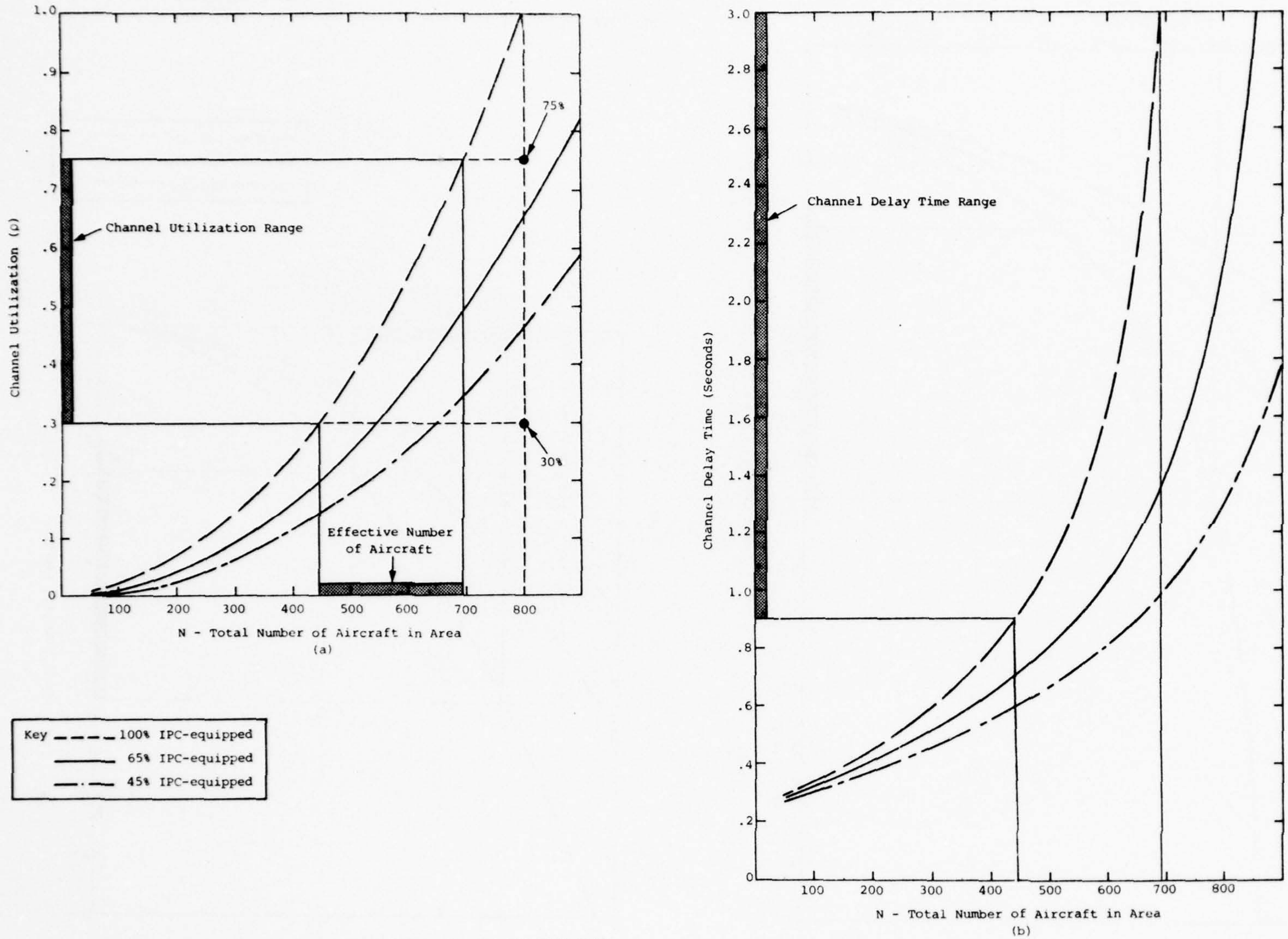


Figure C-1. CHANNEL UTILIZATION AND DELAY OF DEDICATED IFC ONE-WAY DATA LINK (PARAMETER SET A)

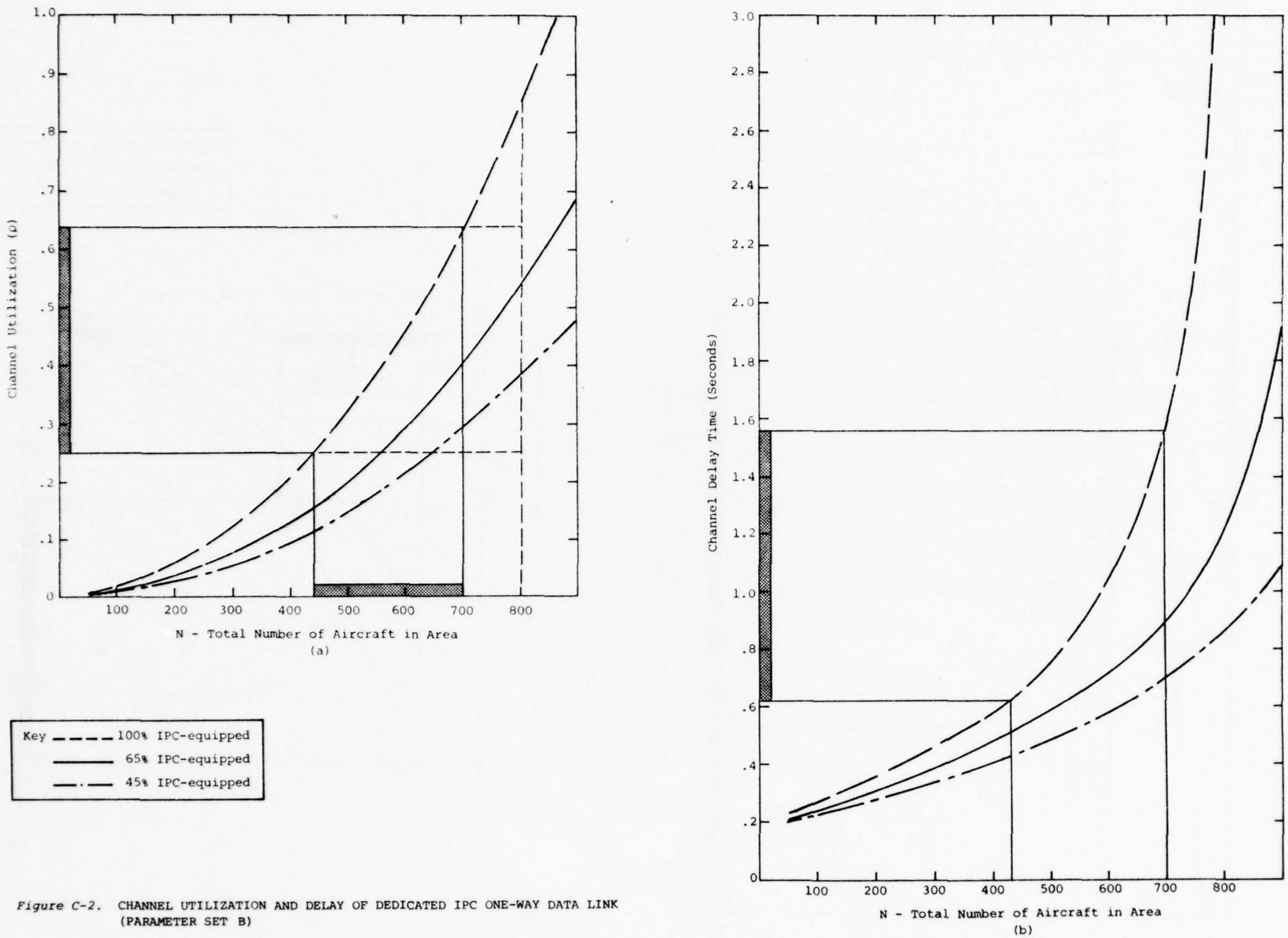


Figure C-2. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC ONE-WAY DATA LINK (PARAMETER SET B)

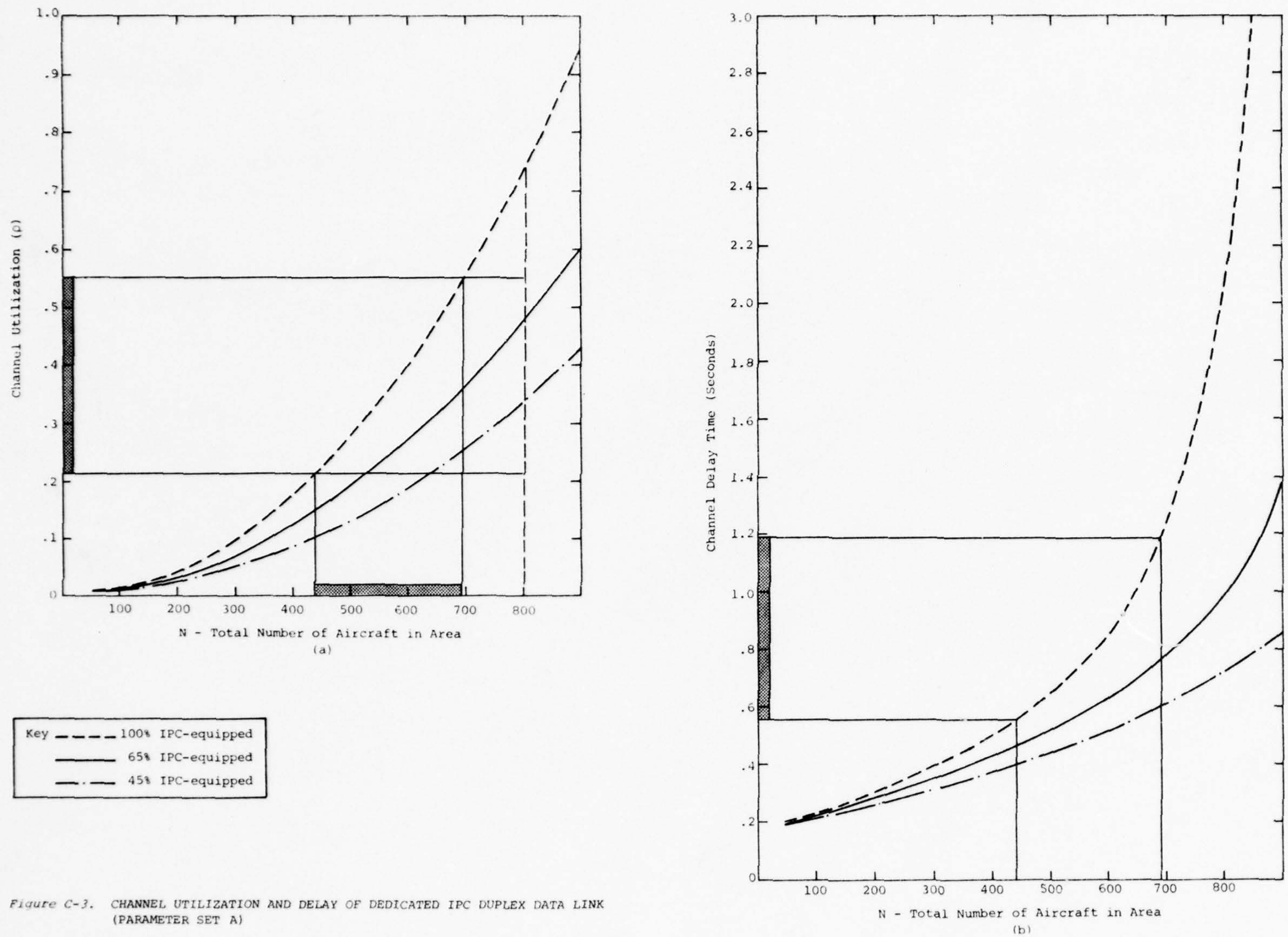


Figure C-3. CHANNEL UTILIZATION AND DELAY OF DEDICATED IPC DUPLEX DATA LINK (PARAMETER SET A)

APPENDIX D

LOGIC SCHEMATIC DIAGRAMS

This appendix presents the schematic diagrams of equipments used in support of the two IPC concepts. It is divided into three sections:

D-1 - IPC Using Dedicated VHF Data Link

D-2 - IPC Using ACARS Data Link

D-3 - IPC Using Mini-ACARS Data Link

APPENDIX D-1

IPC USING DEDICATED VHF DATA LINK

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CIRCUIT DIAGRAM APPLICATIONS AS A FUNCTION OF IMPLEMENTATION OPTIONS				
Schematic	Options			
	Single-Channel Uplink Only	Single Channel Duplex	Multi-Channel Uplink Only	Multi-Channel Duplex
Baseband Demodulator (Figure D-1)	X	X	X	X
Baseband Modulator (Figure D-2)		X		X
Baseband Modulator Timing Diagram (Figure D-3)		X		X
Altitude Discriminator (Figure D-4)			X	X
Timing and Control Circuits (Figure D-5)	X	X	X	X
Timing Diagram (Figure D-6)	X	X	X	X
Pre-Key, Aircraft Identity Detection, and Counter Enabling Circuits (Figure D-7)	X	X	X	X
Block Check Sequence Generator (Figure D-8)	X	X	X	X
IPC Display Logic and Lamp Driver Circuits (Figure D-9)	X	X	X	X

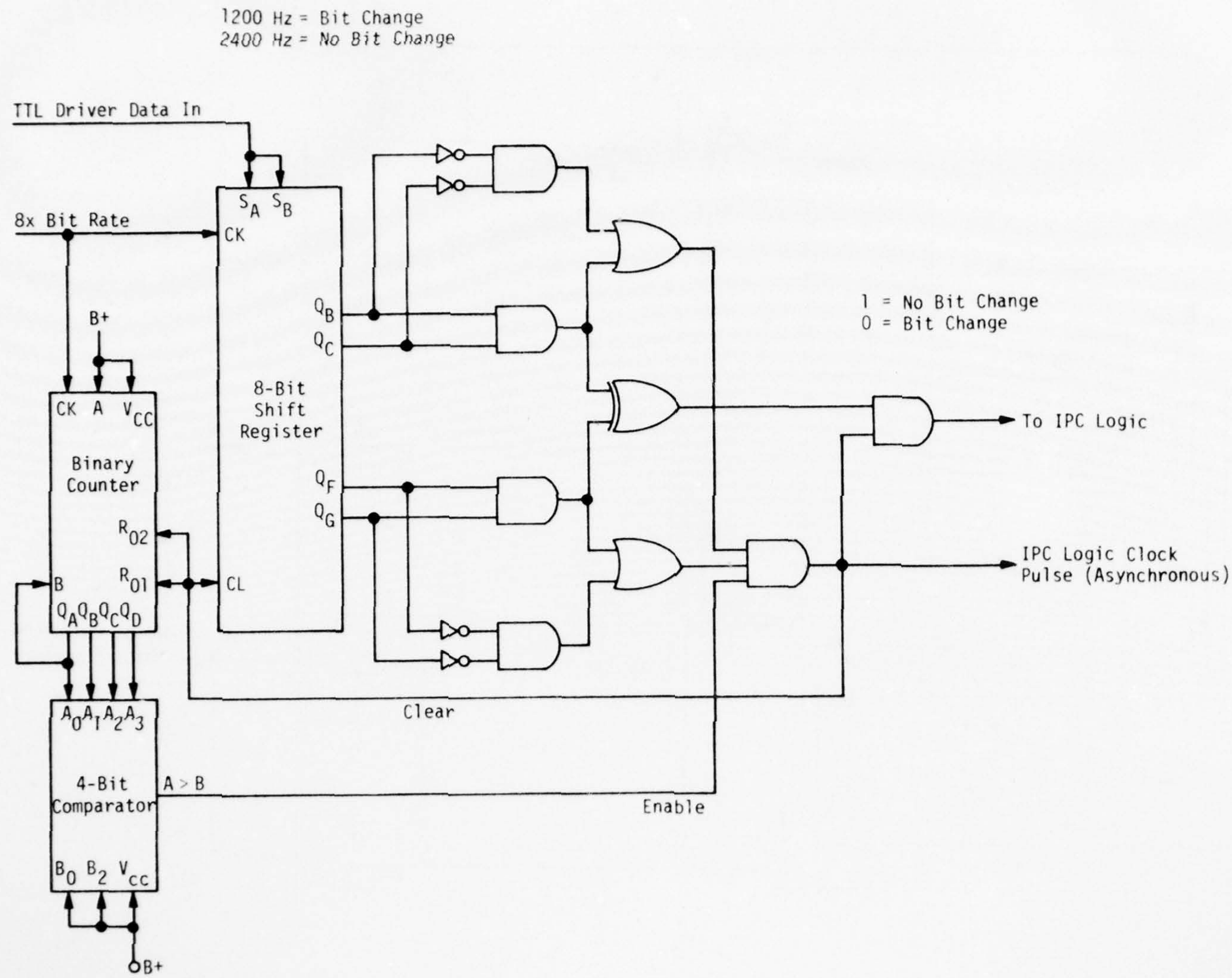

Figure D-1. DFSK BASEBAND DEMODULATOR

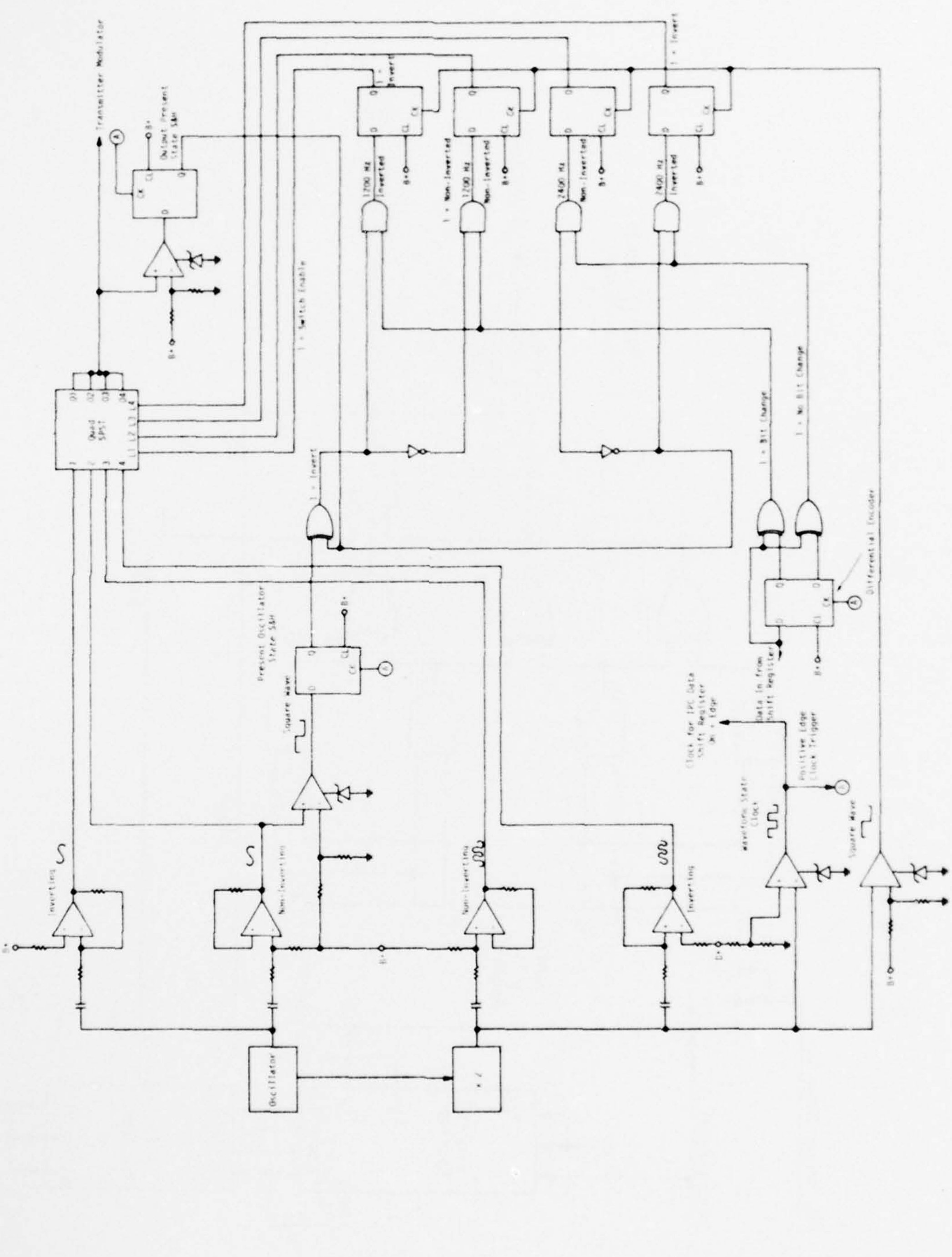

Figure D-2. DFSK BASEBAND MODULATOR

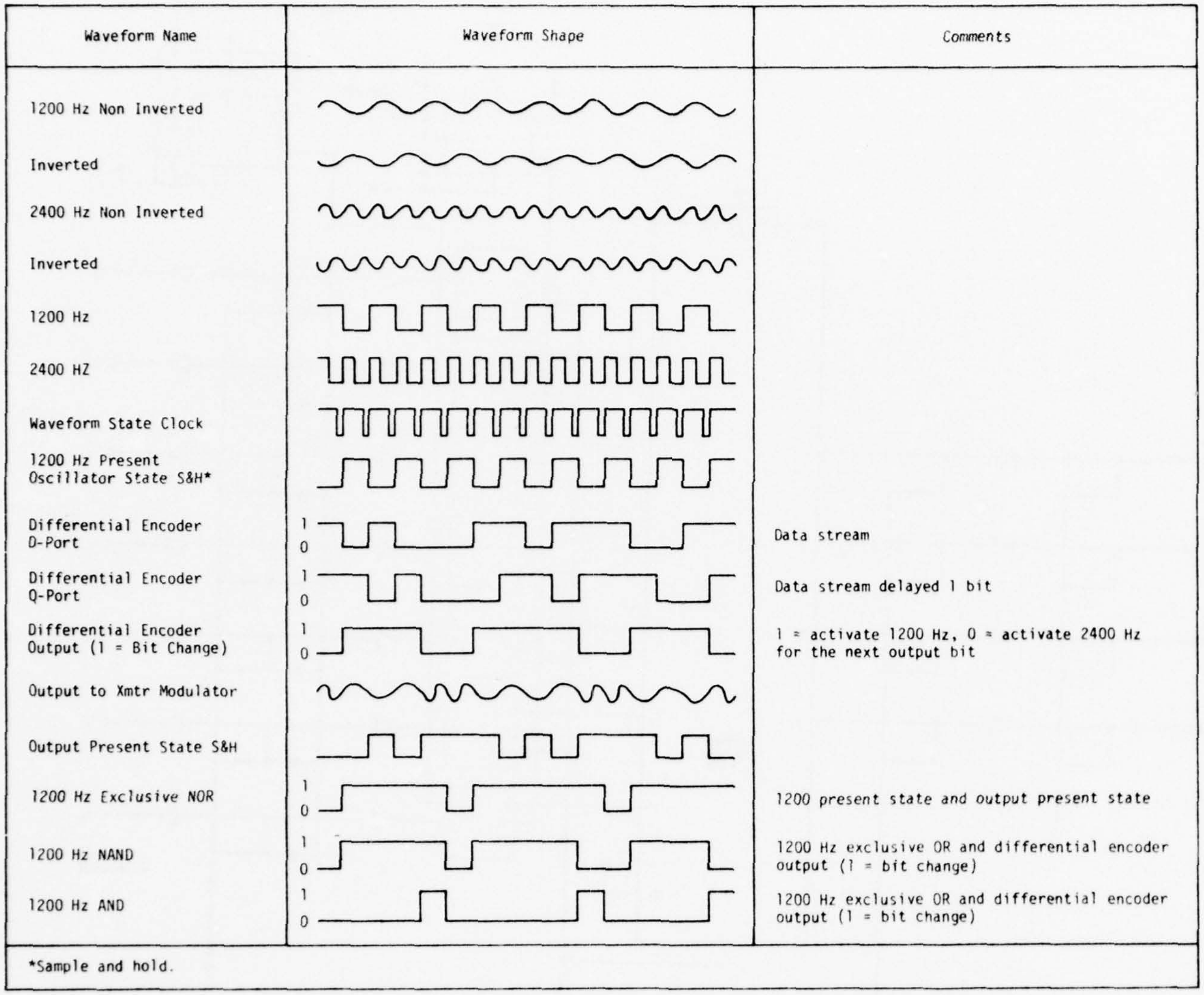

Figure D-3. DFSK BASEBAND MODULATOR TIMING DIAGRAM

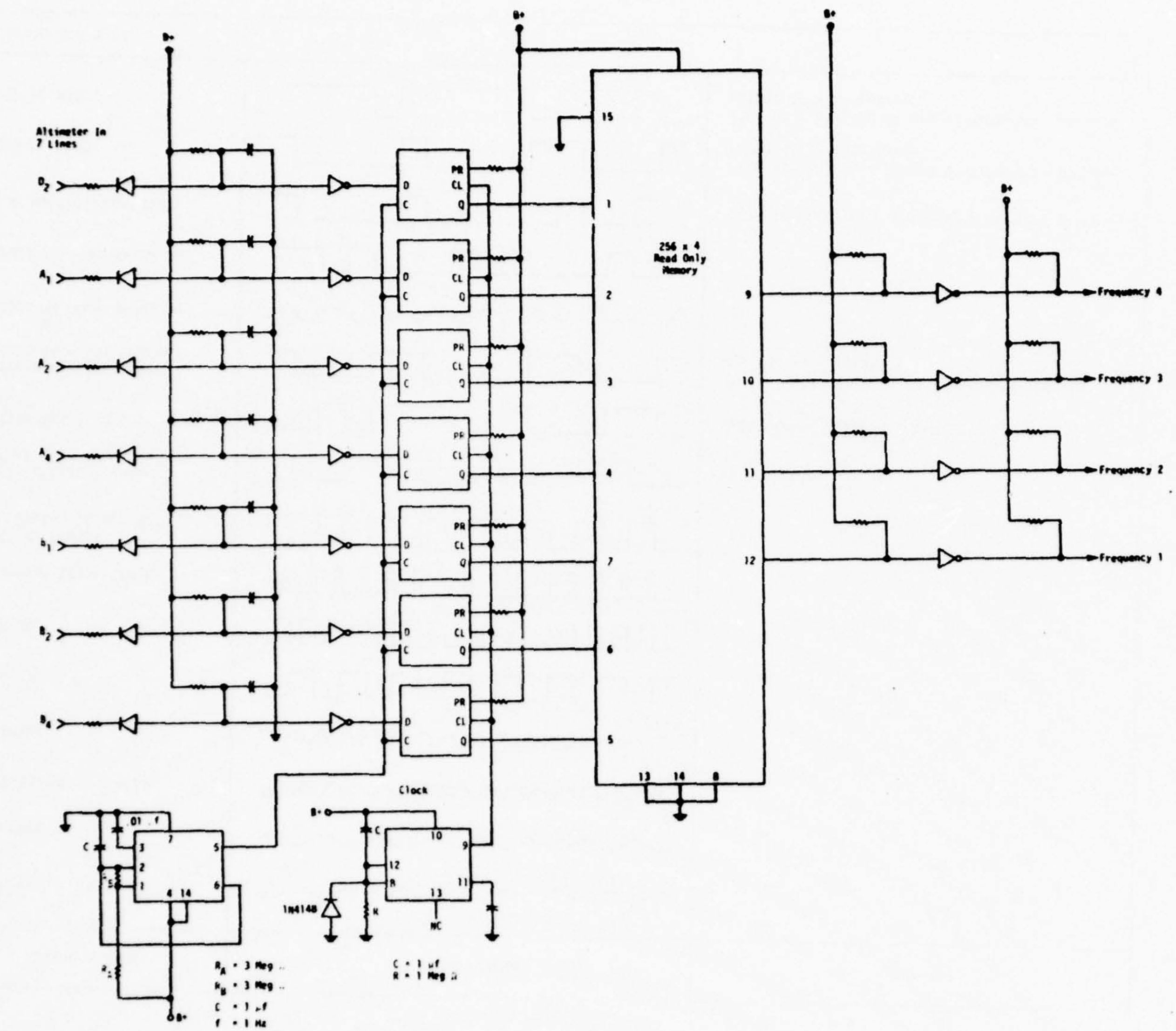

Figure D-4. ALTITUDE DISCRIMINATOR

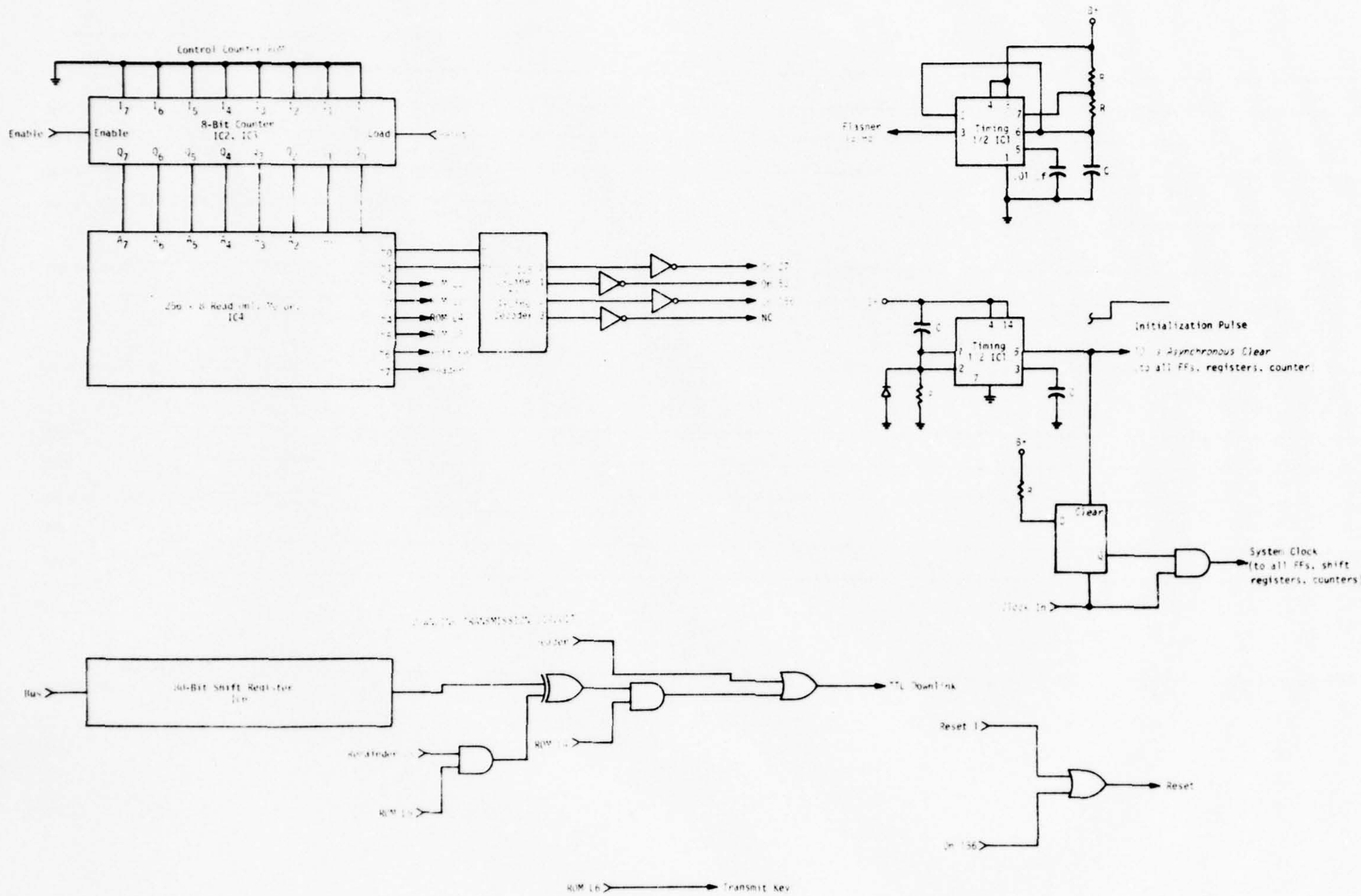

Figure D-5. TIMING AND CONTROL CIRCUITS

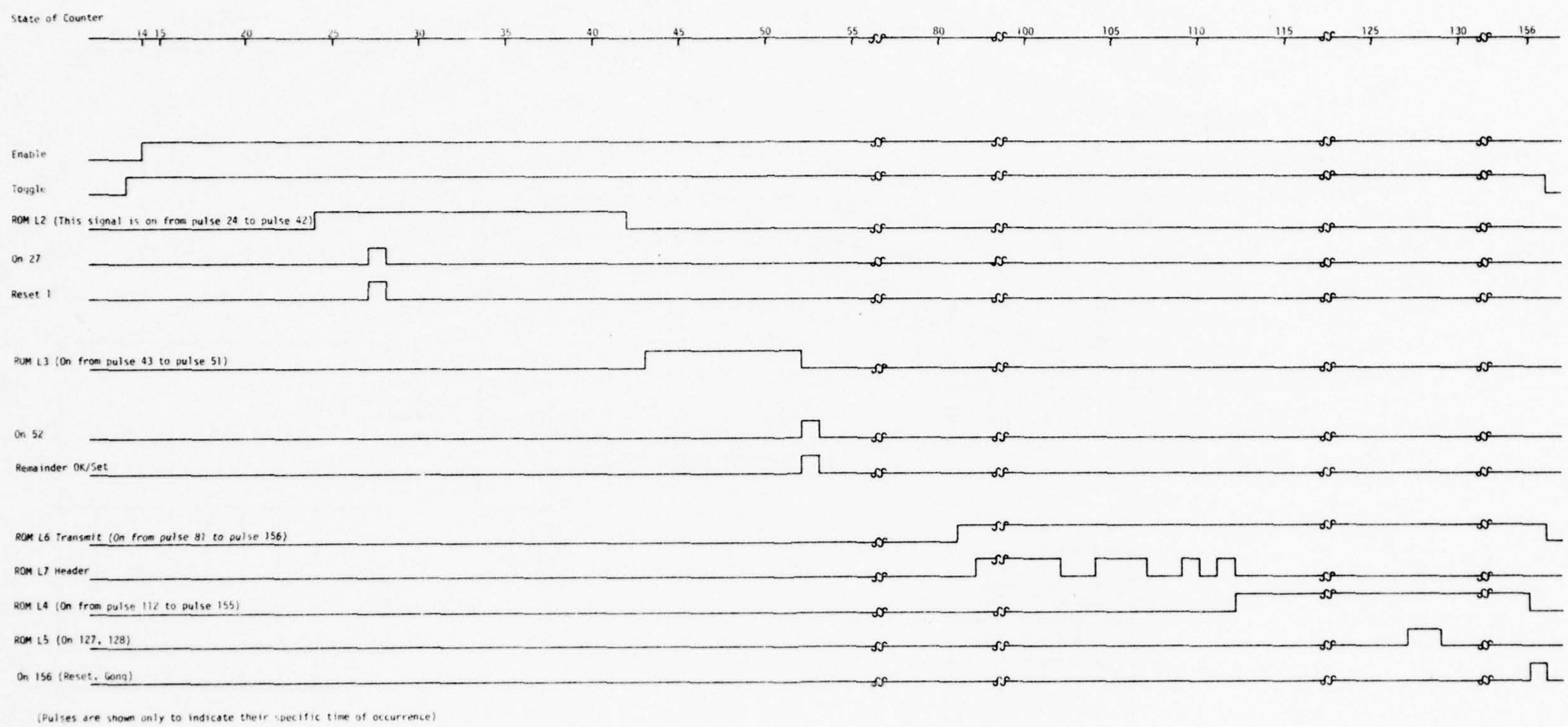

Figure D-6. TIMING DIAGRAM

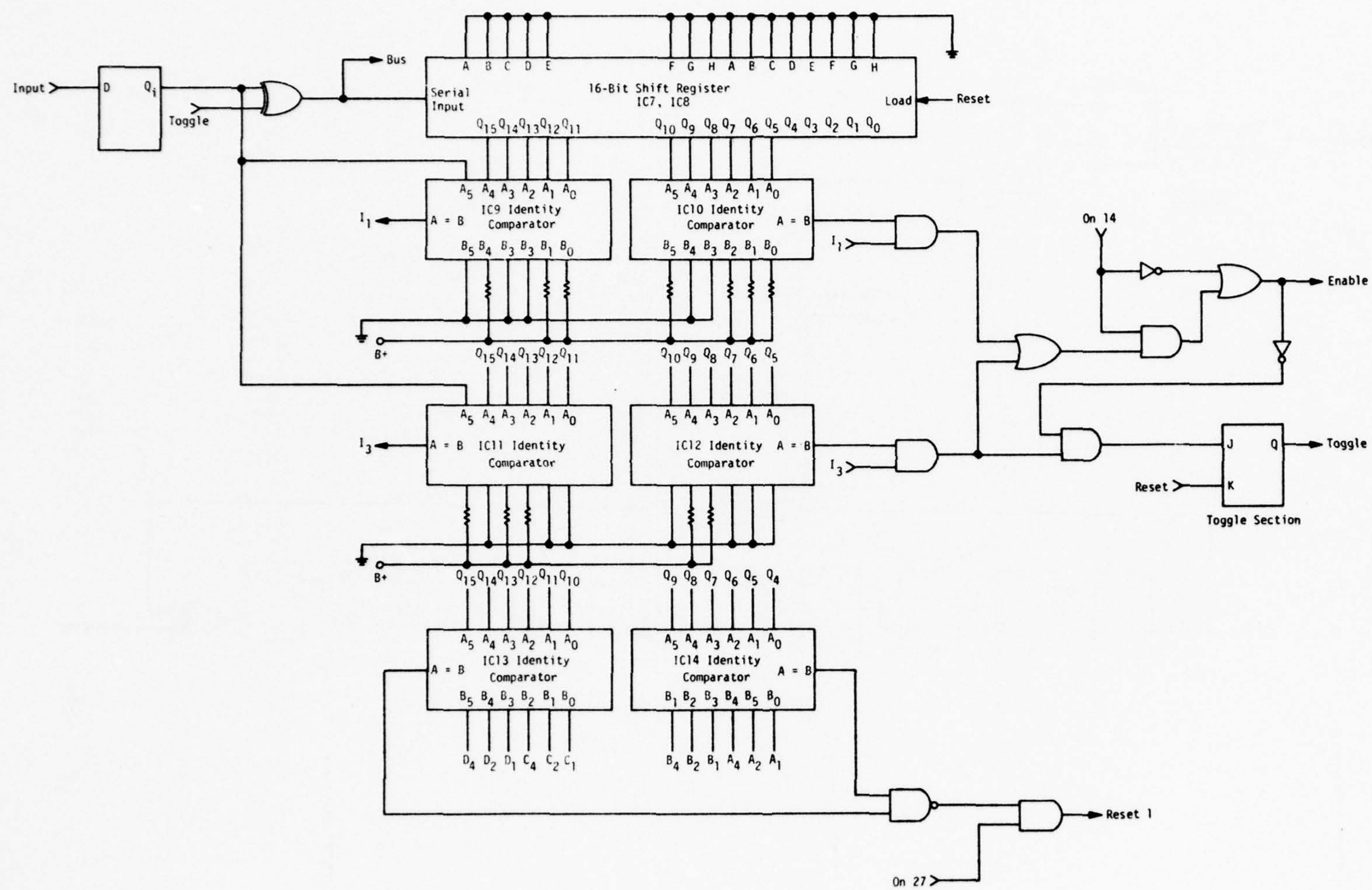

Figure D-7. PRE-KEY, AIRCRAFT IDENTITY DETECTION, AND COUNTER ENABLING CIRCUITS

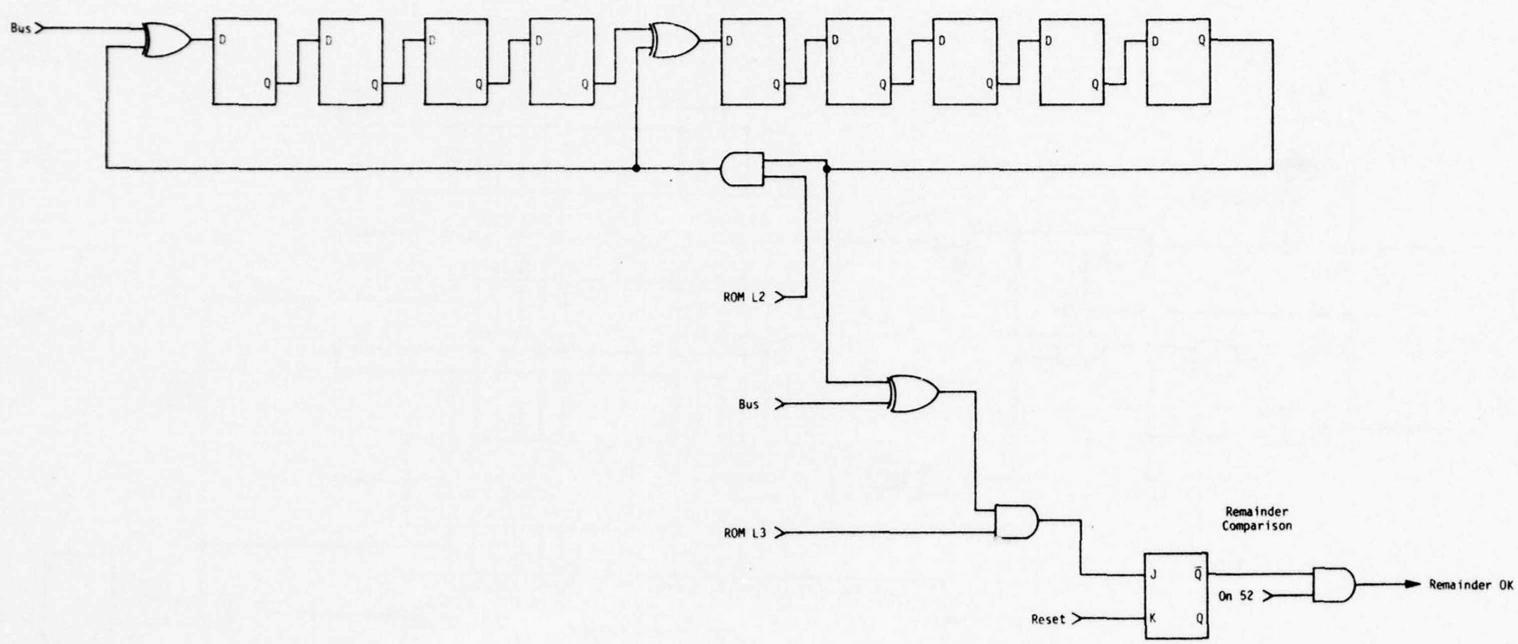

Figure D-8. BLOCK CHECK SEQUENCE (BCS) GENERATOR

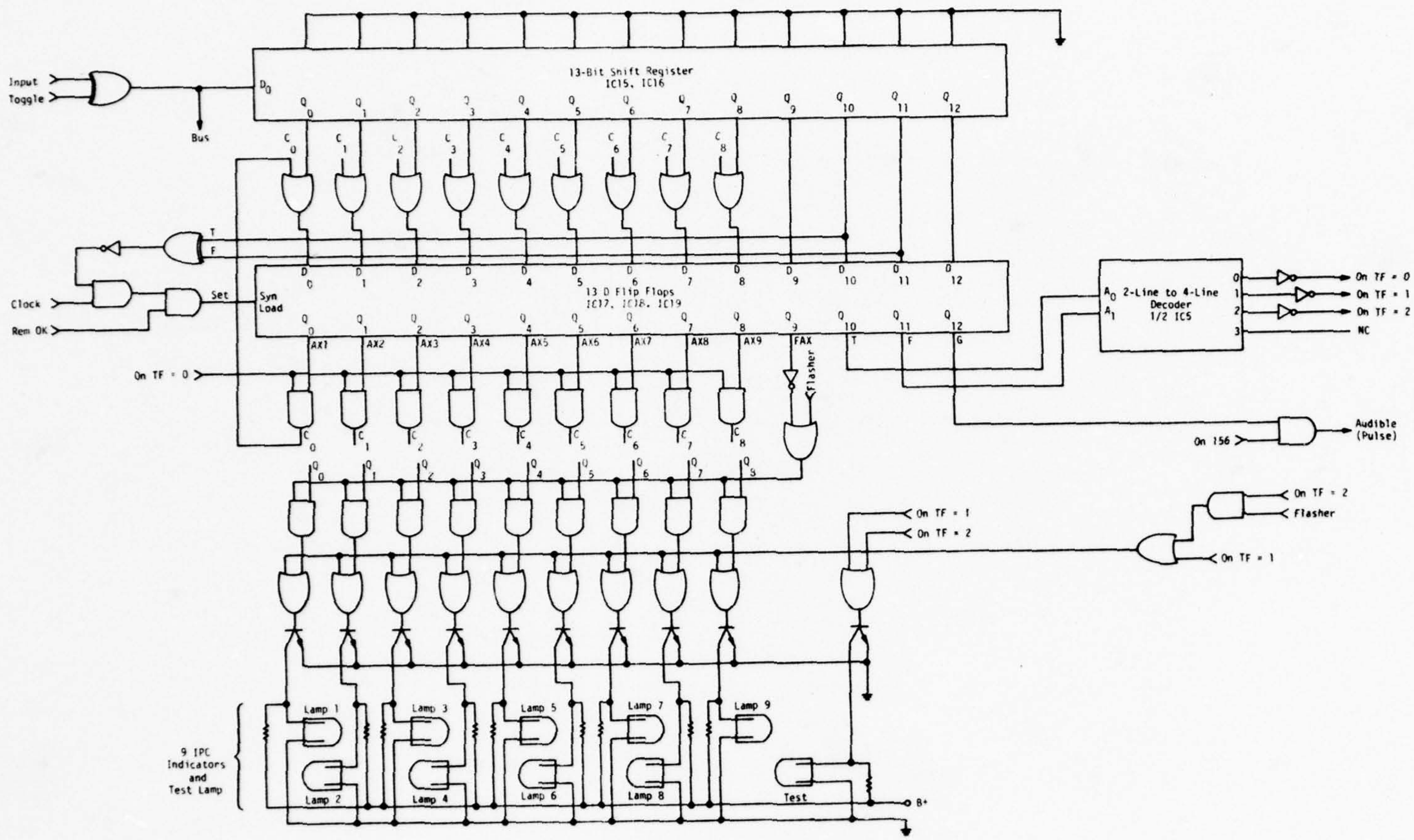

Figure D-9. IPC DISPLAY LOGIC AND LAMP DRIVER CIRCUITS

APPENDIX D-2

IPC USING ACARS DATA LINK

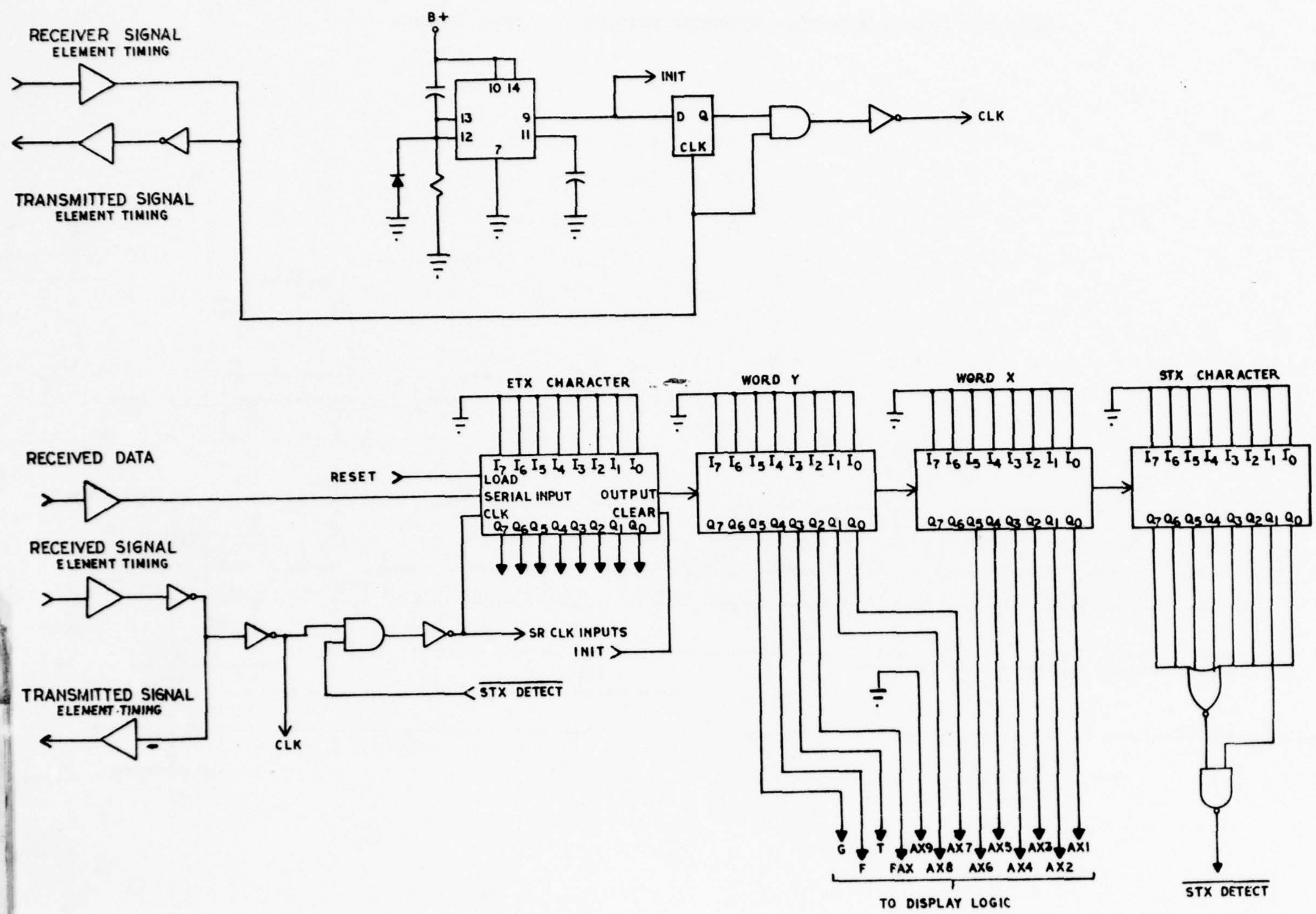

Figure D-10. TIMING AND DECODING LOGIC DIAGRAM

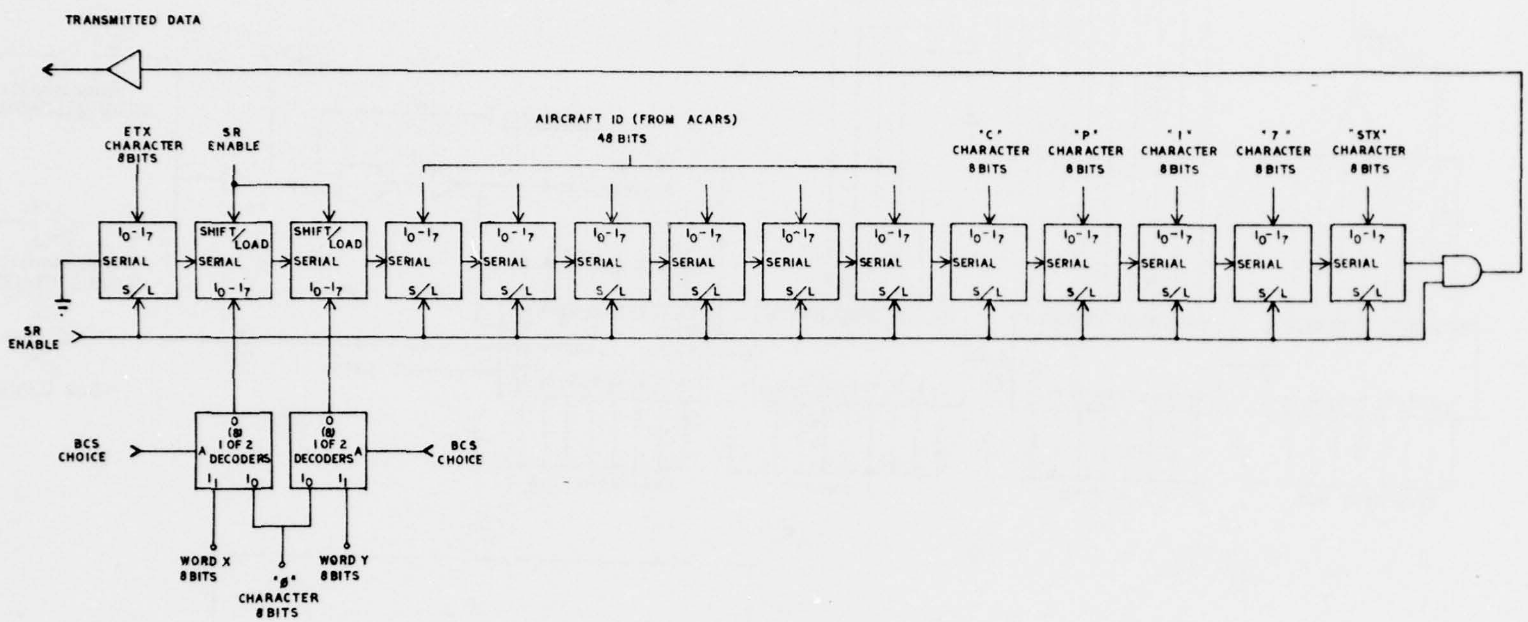

Figure D-11. DOWNLINK MESSAGE ENCODING LOGIC DIAGRAM

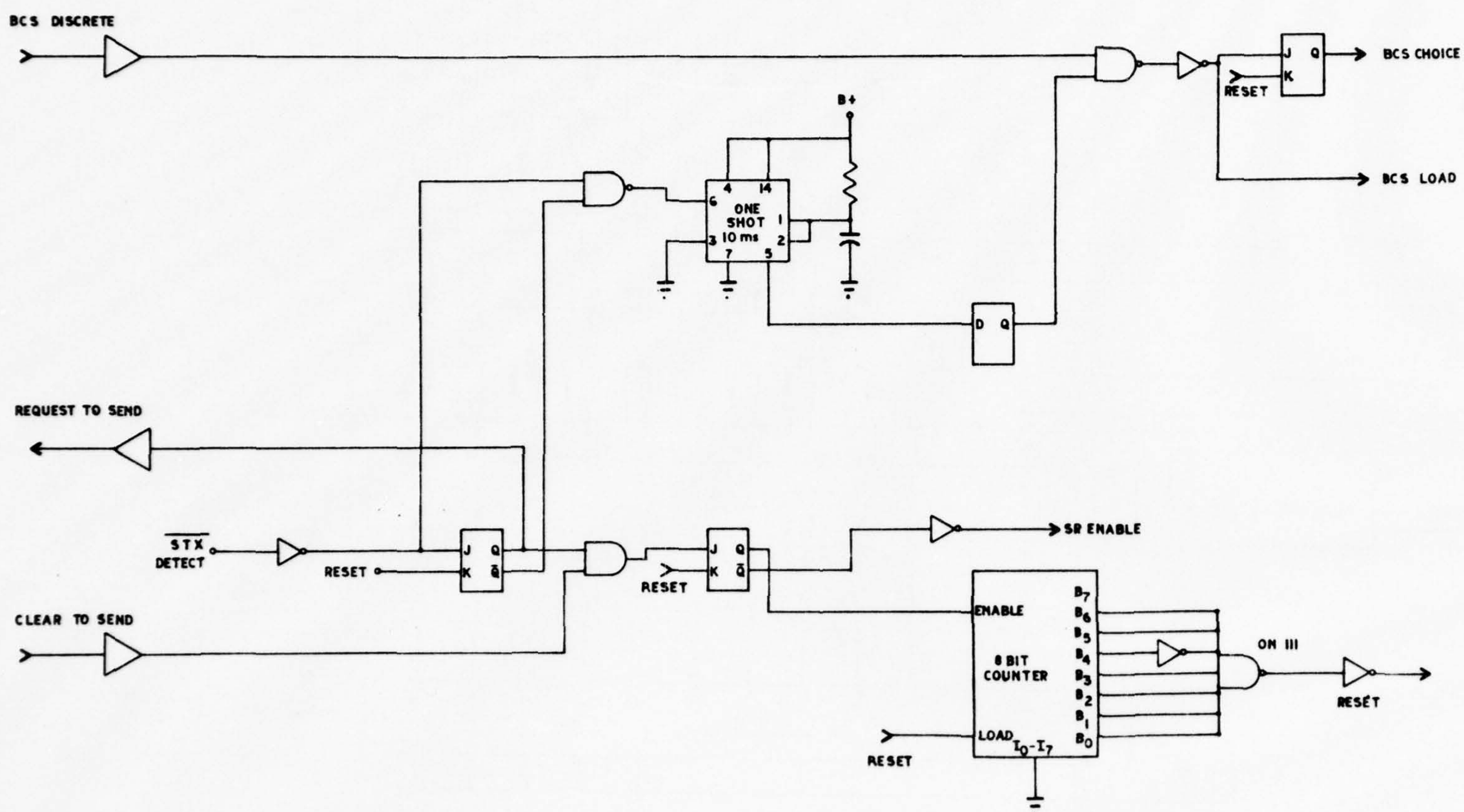

Figure D-12. CONTROL LOGIC DIAGRAM

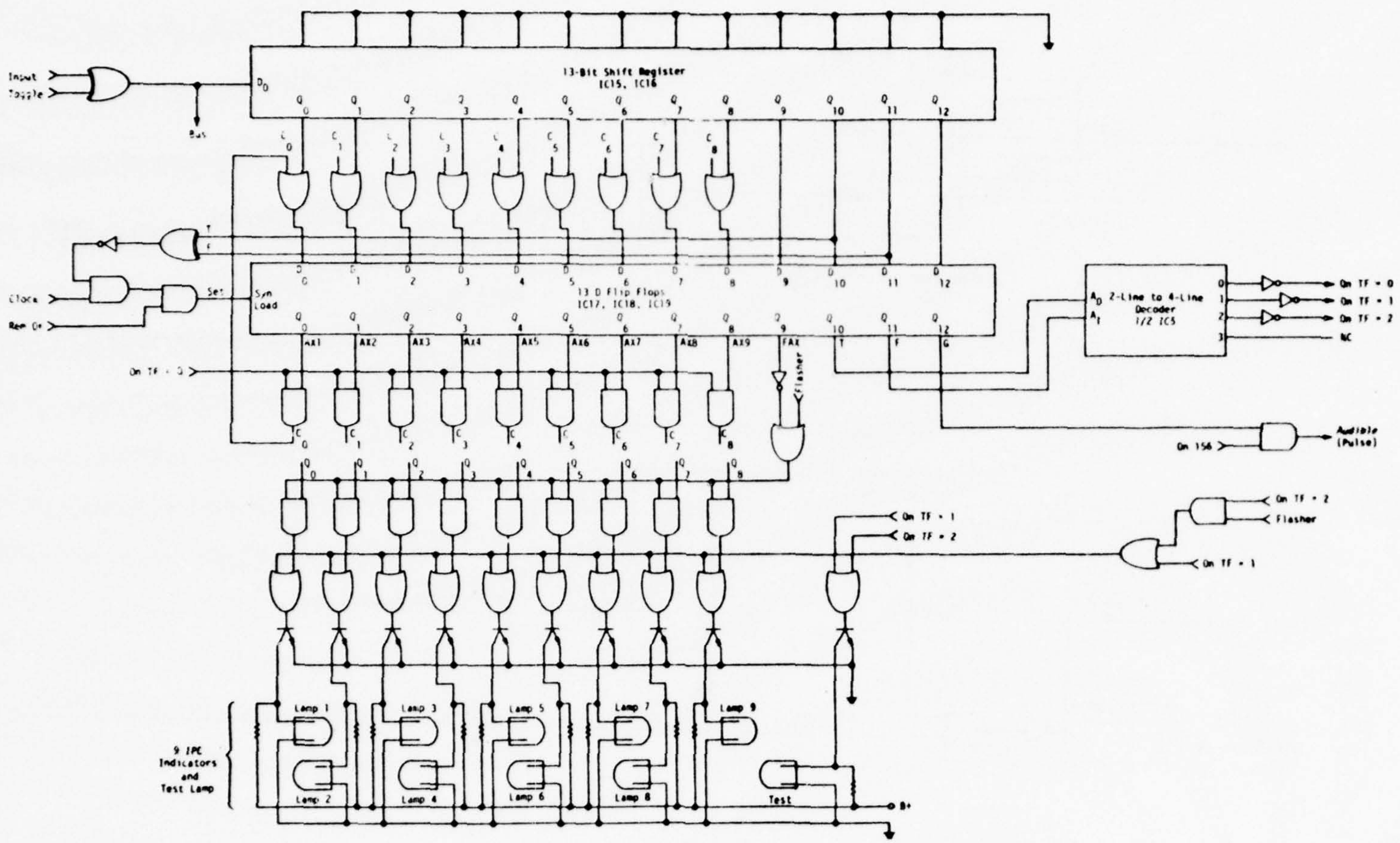

Figure D-13. IPC DISPLAY LOGIC AND LAMP DRIVER CIRCUITS

APPENDIX D-3

IPC USING MINI-ACARS DATA LINK

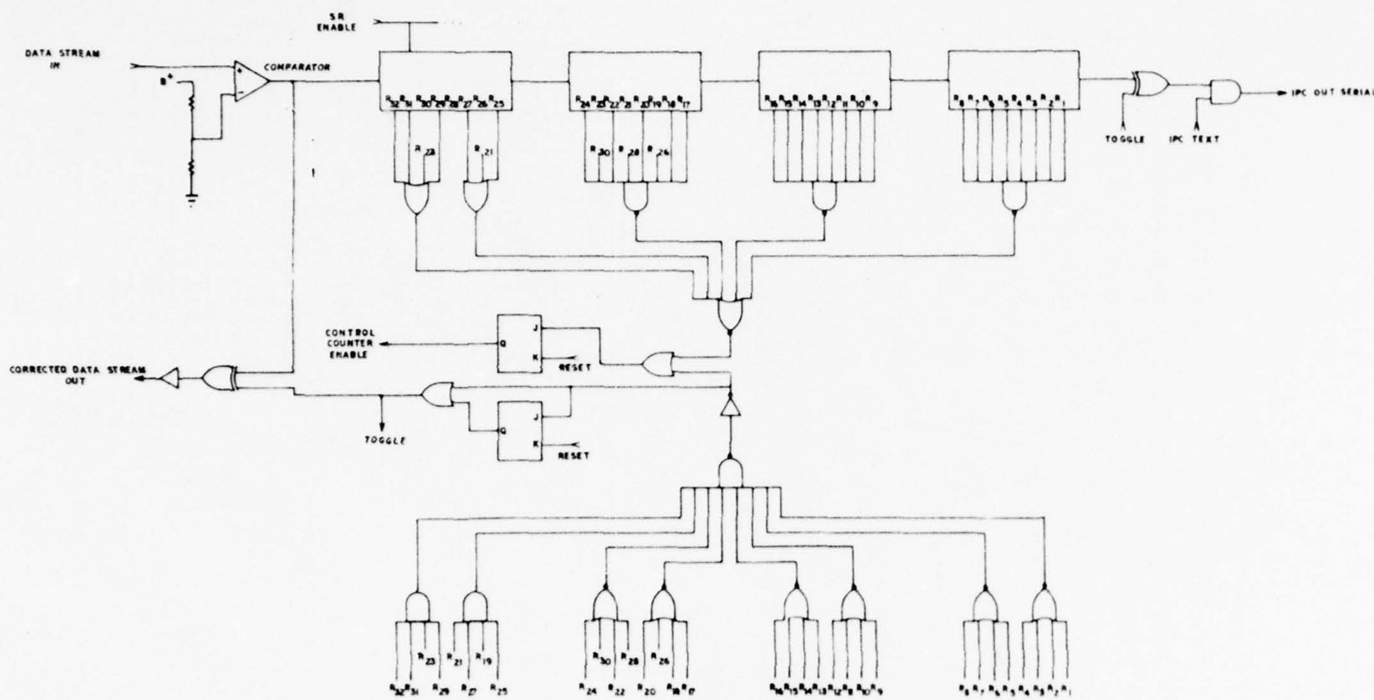

Figure D-14. PRE-KEY AND BIT SYNC DETECTOR LOGIC DIAGRAM

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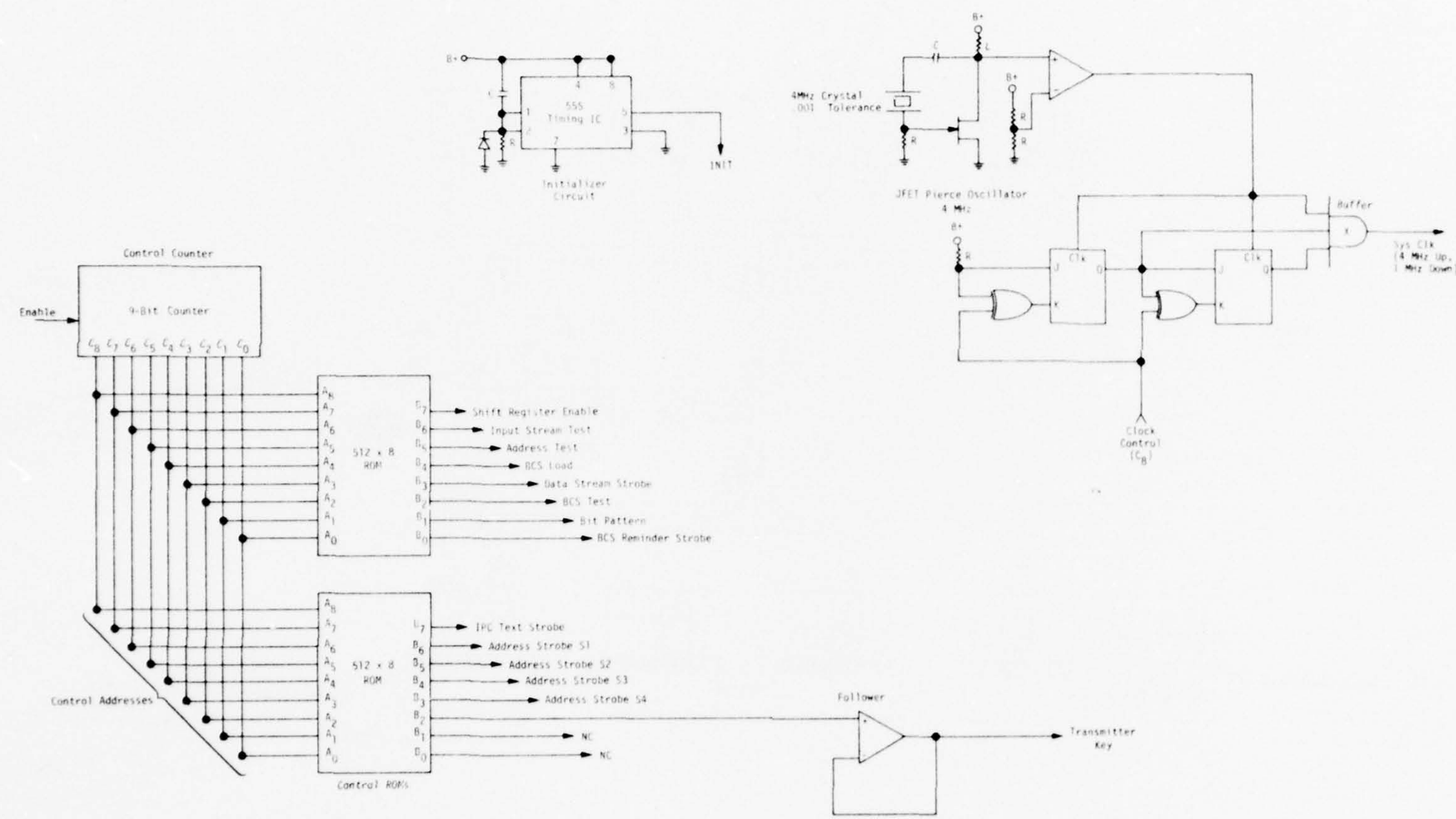

Figure D-15. TIMING AND CONTROL CIRCUITS DIAGRAM

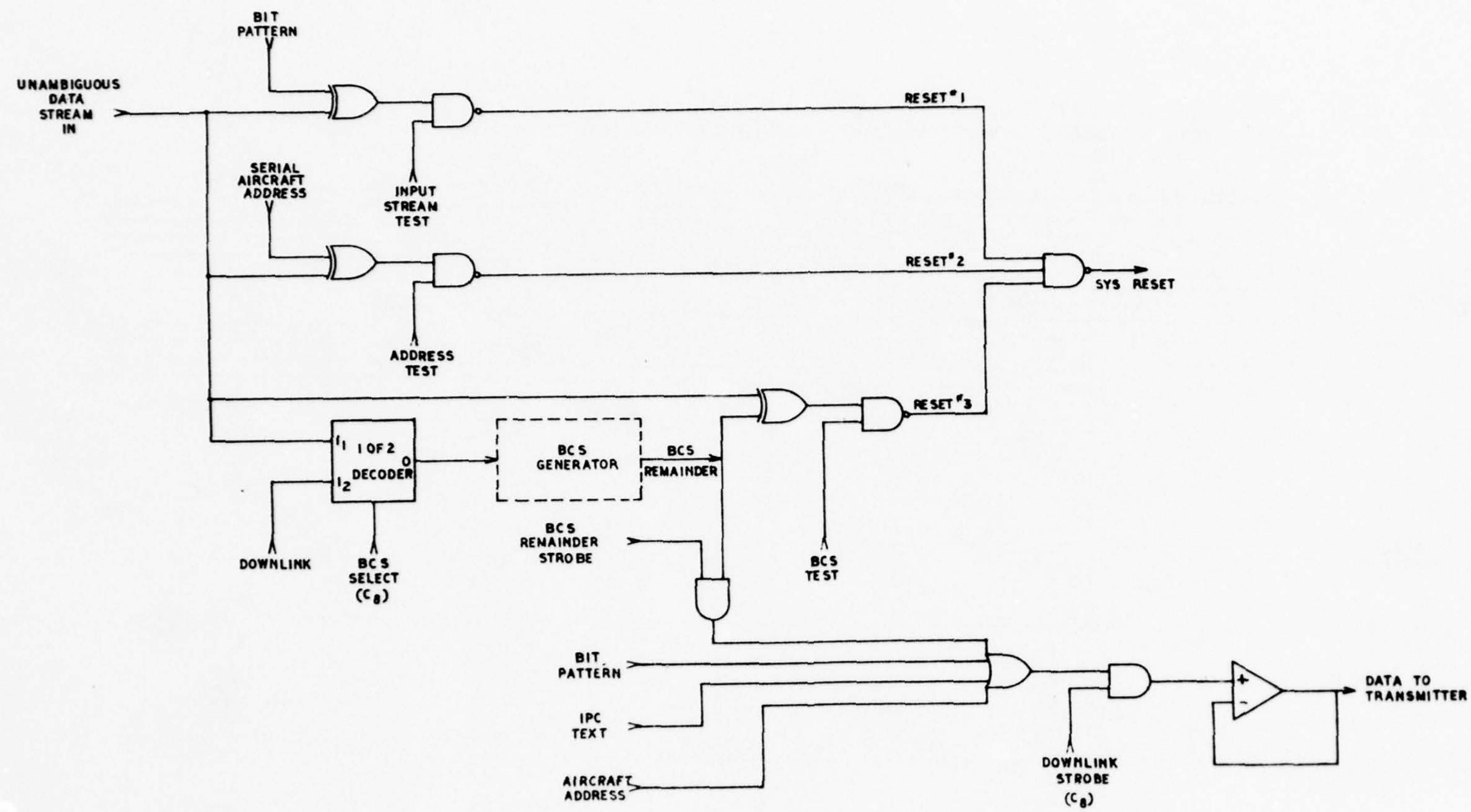

Figure D-16. DOWNLINK MESSAGE ENCODING CIRCUIT DIAGRAM

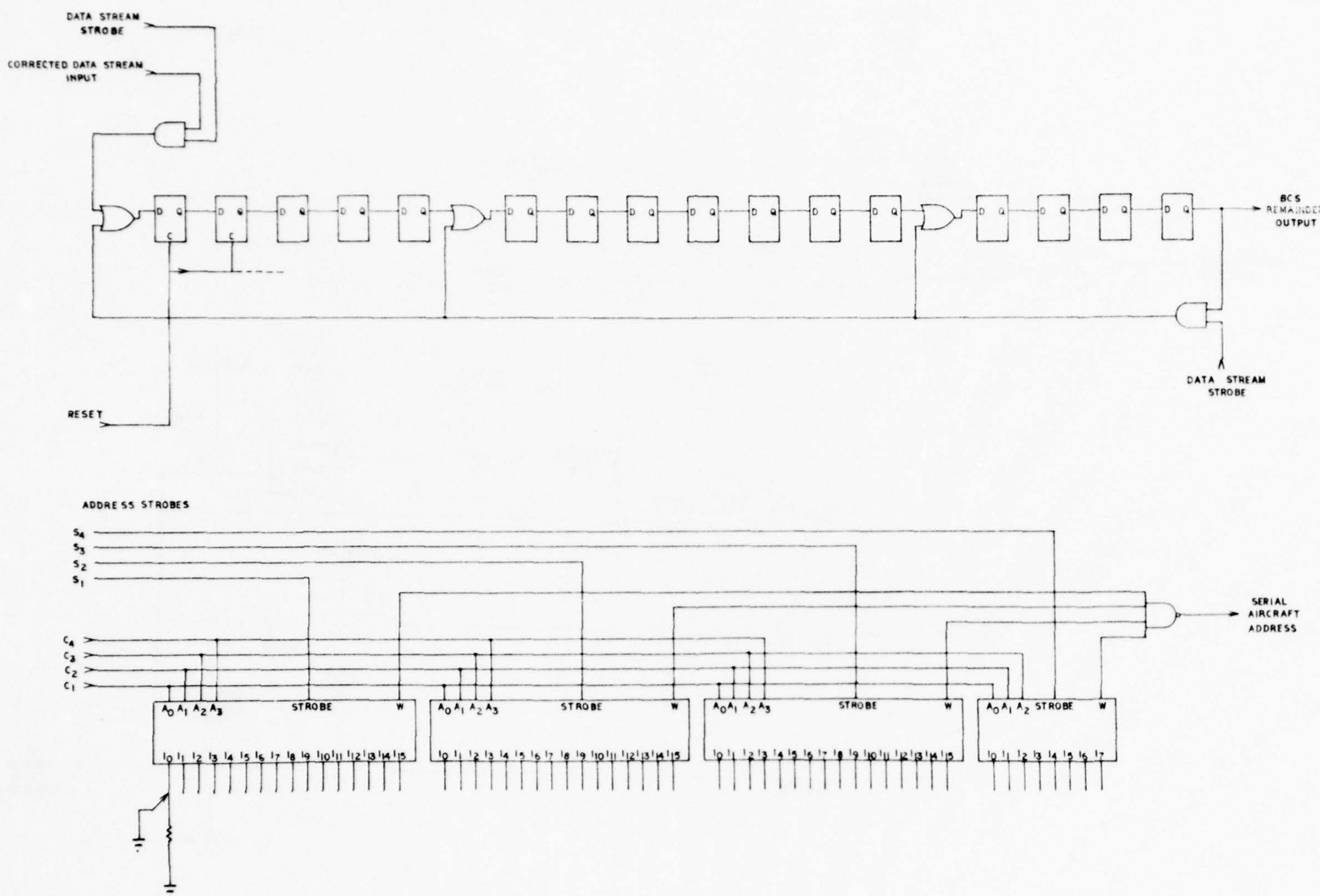

Figure D-17. BLOCK CHECK SEQUENCE GENERATOR AND AIRCRAFT ADDRESS ENCODING LOGIC DIAGRAM

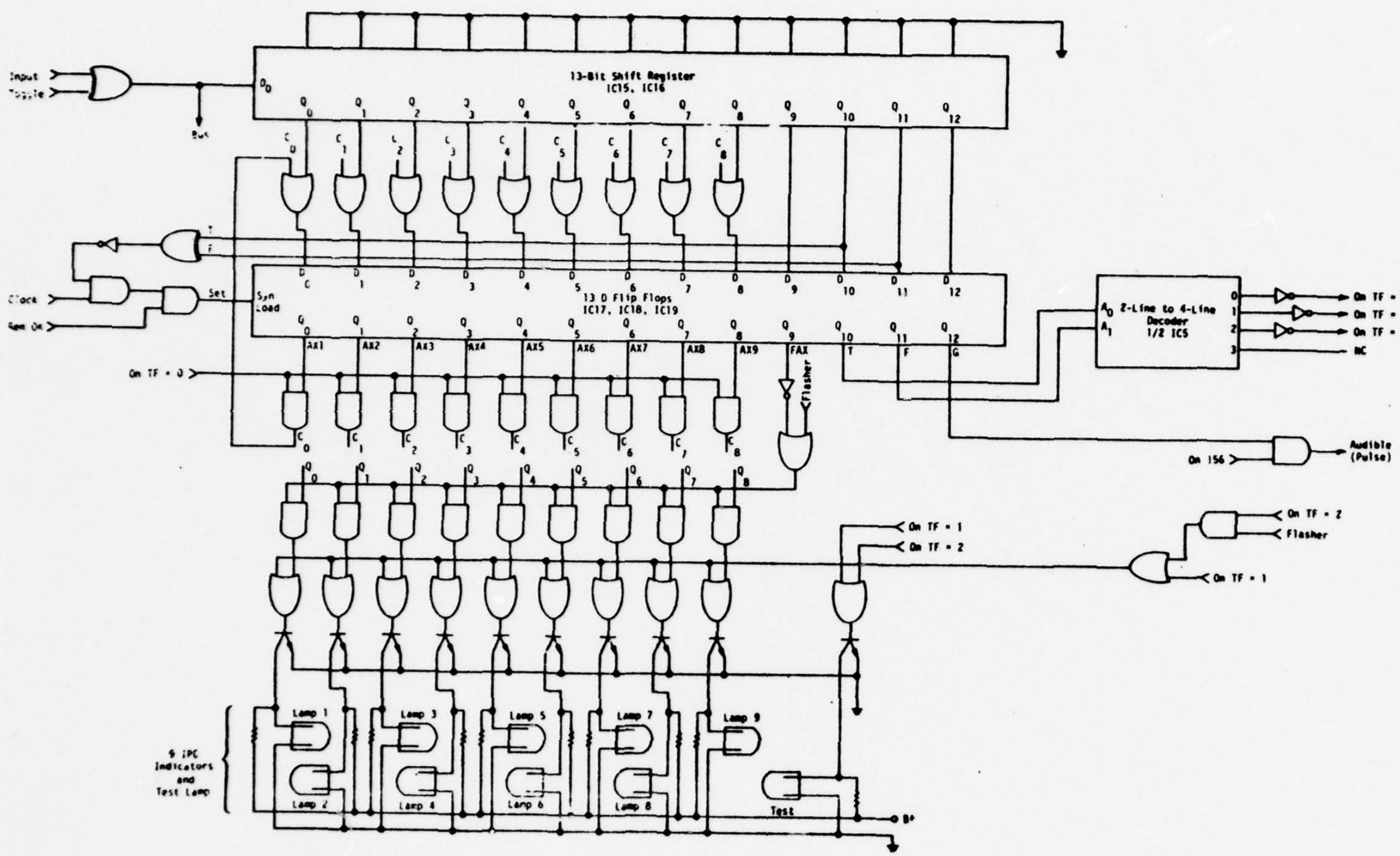

Figure D-18. IPC DISPLAY LOGIC AND LAMP DRIVER CIRCUITS

APPENDIX E

SYSTEM PARTS LISTS AND COST-DEVELOPMENT DATA SHEETS

This appendix contains the worksheets used to develop costs of modules and systems employed in the various concepts and options. These costs were the basis for the calculations presented in the body of the report. The sheets are grouped by system configuration in the eleven sections of this appendix:

APPENDIX E-1

IPC USING A DEDICATED VHF DATA LINK,
SINGLE CHANNEL, UPLINK ONLY,
HIGH PERFORMANCE

SHEET 1 OF 10

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Preselector

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Capacitors	25	.18	4.50		125			
Tun. Coils	4	.35	1.40		60			
Resistors	7	.03	.21		35			
Coils	4	.06	.24		24			
FE Transistion	1	.90	.90		6			
Sil Diode	1	.21	.21		5			
Chassis	1	1.50	1.50	35	25			
Cover	1	.50	.50	15	10			
Misc. Hardware	Lot	.30	.30		50			
Transformer-Mix	2	1.50	3.00		40			
Diodes, Sil	12	2.64	31.68		60			
Tun. Cap.	1	.35	.35		15			
Totals			44.79	50	455 x 1.5 = 683			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY IF Coupler

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Coils	2	.06	.12		12			
Var. Caps	2	.35	.70		30			
Cap.	1	.18	.18		5			
Chassis	1	.50	.50	30	15			
Cover	1	.15	.15	15	10			
Misc. Hardware	Lot	.25	.25		25			
PC Board	1	.75	.75	35	15			
Totals			2.65	80	112 x 1.5 = 168			

SHEET 3 OF 10

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY IF Amplifier

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N4997	1	.40	.40		6			
2N3688	2	.27	.54		12			
2N3906	2	.33	.66		12			
997F-17 TMTR	1	.76	.76		5			
1N270	2	.13	.26		10			
1N816	1	.35	.35		5			
Var. Caps	3	.35	1.05		45			
Caps. Disc	22	.12	2.64		110			
Cap Tant	1	.18	.18		5			
Coils	5	.06	.30		30			
Coil Tipped	1	.35	.35		15			
Resistors	21	.03	.63		105			
Chassis	1	1.25	1.25	75	50			
Cover	1	.35	.35	15	15			
Misc. Hardware	Lot	1.50	1.50		50			
Cap. F/T	7	.11	.77		56			
Totals			11.99	90	531 x 1.5 = 797			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Selectable Attenuator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MPS-H10	2	.33	.66		12			
MPSA 56	1	.37	.37		6			
SMV-307	1	.50	.50		6			
5082-2811	2	.63	1.26		10			
Tun. Coil	1	.35	.35		15			
Coils	2	.06	.12		12			
Cap. T/M	2	.18	.36		10			
Cap. Disc	9	.12	1.08		45			
Resistors	12	.03	.36		60			
Cap F/T	3	.11	.33		24			
PC Board	1	.45	.45	45	50			
Chassis Housing	1	.40	.40	60	40			
Cover	1	.20	.20	15	10			
Misc. Hardware	Lot	.85	.85		45			
Totals			7.29	120	345 x 1.5 = 518			

SHEET 5 OF 10

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY AGC Board

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N2925	1	.22	.22		6			
2N3702	1	.32	.32		6			
2N3906	1	.34	.34		6			
2N3403	1	.32	.32		6			
1N816	1	.25	.25		5			
997F-17	1	.76	.76		5			
Potentiometer	2	.65	1.30		30			
Cap. T/M	6	.18	1.08		30			
Cap. Disc	0	--	--		--			
Resistors	19	.03	.57		95			
Wiring Board	1	.75	.75	50	75			
Misc. Hardware	Lot	1.25	1.25		50			
Freq Control:								
LM107	1	4.25	4.25		8			
2N3823	1	.78	.78		6			
Crystal	1	1.50	1.50		15			
Capacitor	1	.18	.18		5			
Resistors	3	.03	.09		15			
Coil	1	.06	.06		6			
Totals			14.02	50	369 x 1.5 = 554			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
On-Off Relay	1	4.54	4.54		15			
TS-6 Sil Diode	2	.22	.44		10			
2N3440	1	.75	.75		6			
2N3417	2	.30	.60		12			
2N4917	1	.21	.21		6			
2N3789	1	2.45	2.45		6			
2N4871	1	.45	.45		6			
2N3415	2	.20	.40		12			
2N5322	1	1.02	1.02		6			
2N4923	1	.79	.79		6			
1N4735A	1	1.30	1.30		5			
1N4934	1	.35	.35		5			
1N942A	1	3.00	3.00		5			
1N457A	2	.29	.58		10			
1N816	1	.35	.35		5			
Potentiometer	2	1.30	2.60		30			
Coils	4	.06	.24		36			
Caps T/M	8	.18	1.44		40			
Caps Disc	5	.12	.60		40			
Resistors	21	.03	.63		105			
Mounting Board	1	1.00	1.00	50	60			
Misc. Hardware	Lot	2.50	2.50		75			
Toroids	2	6.21	12.42		830			
Totals			38.78	50	1331 x 1.5 = 1,997			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Logic Decoder #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
54L164	1	10.10	10.10		12			
54L93	1	10.35	10.35		12			
54L85	1	7.48	7.48		10			
CD4049	2	1.12	2.24		16			
5408	1	2.65	2.65		8			
5411	1	2.65	2.65		8			
5432	1	2.90	2.90		8			
5486	1	2.75	2.75		8			
5405	1	2.55	2.55		8			
Cap. Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	2.05	2.05		10			
54161	2	15.98	31.96		16			
MCM6830AL	1	12.60	12.60		10			
54155	1	10.34	10.34		10			
54199	2	6.60	13.20		20			
DM7160	6	6.00	36.00		60			
54174	3	7.95	23.85		24			
PC Board	1	5.00	5.00	333	485			
Totals			185.03	333	965 x 1.5 = 1,448			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Logic Decoder #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	2.50	12.50		40			
54107	7	5.20	36.40		70			
5404	2	2.55	5.10		16			
5486	2	2.75	5.50		16			
5432	4	2.90	11.60		32			
5400	1	2.05	2.05		8			
5408	8	2.65	21.20		64			
Resistors	75	.03	2.25		375			
Cap. Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
Totals			102.21	333	1131 x 1.5 = 1,697			

SHEET 9 OF 10

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Audio XFPX1R 100	1	.91	.91		75			
10mHz Crystal Fil	2	24.18	48.36		150			
Main Chassis	1	8.00	8.00	184	44			
Front Panel	1	2.00	2.00	74	22			
Main Cover	1	2.50	2.50	288	94			
DFA Connector	1	11.97	11.97		50			
PC Connector	1	1.67	1.67		15			
Internal Wiring	Lot	1.50	1.50		500			
Misc. Hardware	Lot	4.50	4.50		250			
Totals			81.41	546	1200			

SYSTEM VHF/IPC Receiving System

SUB-ASSEMBLY Assembly and Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Preselector	1				50			
IF Coupler	1				25			
IF Anplifier	1				50			
Sel. Attenuator	1				50			
AGC Board	1				--			
Power Supply	1				--			
Logic Decoder	1				100			
Chassis	1				250			
Functional Test					1000			
Burn-In					1000			
Pwr Sup Calibration					150			
Totals					2675			

APPENDIX E-2

IPC USING A DEDICATED VHF DATA LINK,
MULTI-CHANNEL (ALTITUDE DISCRIMINATING), UPLINK ONLY,
HIGH PERFORMANCE

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY IF Amp.

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N4997	1	.40	.40		6			
2N3688	2	.27	.54		12			
2N3906	2	.33	.66		12			
997F-17	1	.76	.76		5			
1N270	2	.13	.26		10			
1N816	1	.35	.35		5			
Var. Cap	3	.35	1.05		45			
Cap. Disc	22	.12	2.64		110			
Cap. Tant	1	.18	.18		5			
Coils	5	.06	.30		30			
Coil-Tapped	1	.35	.35		15			
Resistors	21	.03	.63		105			
Cap - F/T	7	.11	.11		56			
Chassis	1	1.25	1.25	75	50			
Cover	1	.35	.35	15	15			
Misc. Hardware	Lot	1.50	1.50		50			
TOTALS			11.99	90	531 x 1.5 = 797			

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SHEET 2 OF 11

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Selectable Attenuator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MPS-H10	3	.33	.66		12			
MPS-A56	1	.37	.37		6			
SMV-307	1	.50	.50		6			
5082-2811	2	.63	1.26		10			
Tun. Coil	1	.35	.35		15			
Coil	2	.06	.12		12			
Cap T/M	2	.18	.36		10			
Cap Disc	9	.12	1.08		45			
Resistors	12	.03	.36		60			
Cap F/T	3	.11	.33		24			
Mtg. Board	1	.45	.45	45	50			
Chassis Housing	1	.40	.40	60	40			
Cover	1	.20	.20	15	10			
Misc. Hardware	Lot	.85	.85		45			
TOTALS		.	7.29	120	345 x 1.5 = 518			

SYSTEM VHF/IPC 4 Channel Receiver System

SUB-ASSEMBLY AGC Bd

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N2925	1	.22	.22		6			
2N3702	1	.32	.32		6			
2N3906	1	.34	.34		6			
2N3403	1	.25	.25		6			
1N816	1	.25	.25		5			
997F-17	1	.76	.76		5			
Potentiometer	2	.65	1.30		30			
Cap T/M	6	.18	1.08		30			
Resistors	19	.03	.57		95			
Mtg. Board	1	.75	.75	50	75			
Misc. Hardware	Lot	1.25	1.25		50			
TOTALS			7.16	50	314 x 1.5 = 471			

SYSTEM VHF/IPC 4 Channel Receiver System

SUB-ASSEMBLY Frequency Control

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
93406	1	14.00	14.00		10			
5406	1	5.30	5.30		8			
CD4049	2	1.12	2.24		16			
54L74	4	4.20	16.80		32			
556	1	2.05	2.05		10			
1N457A	7	.35	2.45		35			
Caps - Disc	15	.12	1.80		75			
Resistors	44	.03	1.45		220			
1N4148	1	.13	.13		5			
2N3823	4	.78	3.12		24			
54H52	1	2.05	2.05		8			
LM107	4	4.25	17.00		40			
Crystals	4	1.50	6.00		60			
Coils	4	.06	.24		24			
PC Board	1	2.50	2.50	333	485			
Misc. Hardware	Lot	1.00	1.00		50			
TOTALS			78.13	333	1102 x 1. = 1102			

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Relay ON/OFF	1	4.54	4.54		15			
TS-6	2	.22	.44		10			
2N3440	1	.75	.75		6			
2N3417	2	.30	.60		12			
2N4917	1	.21	.21		6			
2N3789	1	2.45	2.45		6			
2N4871	1	.45	.45		6			
2N3415	2	.20	.40		12			
2N5322	1	1.02	1.02		6			
2N4923	1	.79	.79		6			
1N4735A	1	1.30	1.30		5			
1N4934	1	.35	.35		5			
1N942A	1	3.00	3.00		5			
1N457A	2	.29	.58		10			
1N816	1	.35	.35		5			
Potentiometer	2	1.30	2.60		30			
Coils	4	.06	.24		36			
Cap T/M	8	.18	1.44		40			
Cap-Disc	5	.12	.60		40			
Resistors	21	.03	.63		105			
Mtg. Board	1	1.00	1.00	50	60			
Misc. Hardware	Lot	2.50	2.50		75			
Toroids	2	6.21	12.42		830			
TOTALS			38.66	50	1331 x 1.5 =1997			

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Logic Decoder #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
54L164	1	10.10	10.10		12			
54L93	1	10.35	10.35		12			
54L85	1	7.48	7.48		10			
CD4049	2	1.12	2.24		16			
5408	1	2.65	2.65		8			
5411	1	2.65	2.65		8			
5432	1	2.90	2.90		8			
5486	1	2.75	2.75		8			
5405	1	2.55	2.55		8			
Cap - Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	2.05	2.05		10			
54161	2	15.98	31.96		16			
MCM6830AL	1	12.60	12.60		10			
54155	1	10.34	10.34		10			
54199	2	6.60	13.20		20			
DM7160	6	6.00	36.00		60			
54174	3	7.95	23.85		24			
PC Board	1	5.00	5.00	333	485			
TOTALS			185.03	333	965 x 1.5 = 1448			

SHEET 7 OF 11

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Logic Decoder #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	2.50	12.50		40			
54107	7	5.20	36.40		70			
5404	2	2.55	5.10		16			
5486	2	2.75	5.50		16			
5432	4	2.90	11.60		32			
5400	1	2.05	2.05		8			
5408	8	2.65	21.20		64			
Resistors	75	.03	2.25		375			
Cap-Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00		485			
TOTALS			102.21	333	1131 x 1.5 = 1697			

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Audio Xfmr.	1	.91	.91		75			
10mHz Filter	2	24.18	48.36		150			
Main Chassis	1	8.00	8.00	184	44			
Front Panel	1	2.00	2.00	74	22			
Main Cover	1	2.50	2.50	288	94			
DPA Conn.	1	11.97	11.97		50			
PC Connector	2	1.67	3.34		30			
Internal Wiring	Lot	1.50	1.50		500			
Misc. Hardware	Lot	4.50	4.50		250			
TOTALS			83.08	546	1215			

SYSTEM VHF/IPC-4 Channel Receiver System

SUB-ASSEMBLY Assembly & Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Preselector	1				50			
IF Coupler	1				25			
IF Amp	1				50			
Sel. Attenuator	1				50			
AGC Board	1				-			
Freq. Control	1				100			
Power Supply	1				-			
Logic Decoder	1				100			
Chassis	1				250			
Pwr. Sup. Calib.					150			
Functional Test					1000			
Burn-In					1000			
TOTALS					2775			

SYSTEM VHF/IPC-4 Channel Receiving System

SUB-ASSEMBLY Preselector

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
SMV-307	16	.50	8.00		80			
Capacitors	9	.18	1.62		45			
Tun Coils	4	.35	1.40		60			
Resistors	7	.03	.21		35			
Coils	4	.06	.24		24			
FE Transistors	1	.90	.90		6			
Sil. Diodes	1	.21	.21		5			
Transformer	2	1.50	3.00		40			
Matche Sil.Diodes	12	2.64	31.68		60			
Tun. Cap	1	.35	.35		15			
Chassis	1	1.50	1.50	35	25			
Cover	1	.50	.50	15	10			
Misc. Hardware	Lot	.30	.30		50			
TOTALS			49.91	50	455 x 1.5 = 683			

SHEET 11 OF 11

SYSTEM VHF/IPC-4 Channel Receiving System

SUB-ASSEMBLY IF Coupler

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Coils	2	.06	.12		12			
Var. Cap	2	.35	.70		30			
Cap	1	.18	.18		5			
Chassis	1	.50	.50	30	15			
Cover	1	.15	.15	15	10			
Comp. Board	1	.75	.75	35	15			
Misc. Hardware	Lot	.25	.25		25			
TOTALS			2.65	80	112 x 1.5 = 168			

APPENDIX E-3

IPC USING A DEDICATED VHF DATA LINK,
SINGLE CHANNEL DUPLEX,
HIGH PERFORMANCE

SHEET 1 OF 12

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Preselector

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Capacitors	25	.18	4.50		125			
Tun. Coils	4	.35	1.40		60			
Resistors	7	.03	.21		35			
Coils	4	.06	.24		24			
F/E Transistor	1	.90	.90		6			
Sil. Diode	1	.21	.21		5			
Chassis	1	1.50	1.50	35	25			
Cover	1	.50	.50	15	10			
Misc. Hardware	Lot	.30	.30		50			
Transformer-Mix	2	1.50	3.00		40			
Diodes-Silicon	12	2.64	31.68		60			
Tun. Cap.	1	.35	.35		15			
TOTALS			44.79	50	455 x 1.5 = 683			

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SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY IF Coupler

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Coils	2	.06	.12		12			
Var. Caps	2	.35	.70		30			
Cap.	1	.18	.18		5			
Chassis	1	.50	.50	30	15			
Cover	1	.15	.15	15	10			
Misc. Hardware	Lot	.25	.25		25			
PC Board	1	.75	.75	35	15			
TOTALS			2.65	80	112 x 1.5 = 168			

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY IF Amplifier

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N4997	1	.40	.40		6			
2N3688	2	.27	.54		12			
2N3906	2	.33	.66		12			
997F-17 TMTR	1	.76	.76		5			
1N270	2	.13	.26		10			
1N816	1	.35	.35		5			
Var. Caps	3	.35	1.05		45			
Caps. Disc	22	.12	2.64		110			
Cap Tant	1	.18	.18		5			
Coils	5	.06	.30		30			
Coil-Tapped	1	.35	.35		15			
Resistors	21	.03	.63		105			
Chassis	1	1.25	1.25	75	50			
Cover	1	.35	.35	15	15			
Misc. Hardware	Lot	1.50	1.50		50			
Cap. F/T	7	.11	.77		56			
TOTALS			11.99	90	531 x 1.5 = 797			

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Selectable Attenuator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MPS-H10	2	.33	.66		12			
MPSA 56	1	.37	.37		6			
SMV-307	1	.50	.50		6			
5082-2811	2	.63	1.26		10			
Tun. Coil (31d)	1	.35	.35		15			
Coils	2	.06	.12		12			
Cap. T/M	2	.18	.36		10			
Cap. Disc	9	.12	1.08		45			
Resistors	12	.03	.36		60			
Cap. F/T	3	.11	.33		24			
PC Board	1	.45	.45	45	50			
Chassis Housing	1	.40	.40	60	40			
Cover	1	.20	.20	15	10			
Misc. Hardware	Lot	.85	.85		45			
TOTALS			7.29	120	345 x 1.5 = 518			

SHEET 5 OF 12

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY AGC Board

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N2925	1	.22	.22		6			
2N3702	1	.32	.32		6			
2N3906	1	.34	.34		6			
2N3403	1	.32	.32		6			
1N816	1	.25	.25		5			
997F-17	1	.76	.76		5			
Potentiometer	2	.65	1.30		30			
Cap. T/M	6	.18	1.08		30			
Cap. Disc	0	--	--		--			
Resistors	19	.03	.57		95			
Wiring Board	1	.75	.75	50	75			
Misc. Hardware	Lot	1.25	1.25		50			
Freq. Control:								
LM107	2	4.25	8.50		16			
2N3823	2	.78	1.56		12			
Crystal	2	1.50	3.00		30			
Capacitor	2	.18	.36		10			
Resistors	6	.03	.18		30			
Coil	2	.06	.12		12			
TOTALS			20.88	50	424 x 1.5 = 636			

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Power Supply-Modulator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
On-Off Relay	1	4.54	4.54		15			
2N3440	1	.75	.75		6			
2N3417	2	.30	.60		12			
2N4917	3	.21	.63		18			
2N3789	1	2.45	2.45		6			
2N4871	1	.45	.45		6			
2N3415	3	.20	.60		18			
2N5322	1	1.02	1.02		6			
2N4923	2	.79	1.58		12			
2N4399	1	5.40	5.40		6			
1N5344B	1	1.67	1.67		5			
1N4735A	1	1.30	1.30		5			
1N4934	2	.35	.70		10			
1N942A	1	3.00	3.00		5			
1N457A	2	.29	.58		10			
1N816	1	.35	.35		5			
Potentiometer	2	1.30	2.60		30			
Coils	4	.06	.24		24			
Cap. Elect	3	1.55	4.65		45			
Cap. Tant	8	.18	1.44		40			
Cap. Disc	15	.12	1.80		75			
Resistors	62	.03	1.86		310			
(continued) TOTALS								

SHEET 7 OF 12

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Power Supply-Modulator (continued)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Toroids	2	6.21	12.42		830			
Fuse-2A	1	.81	.81		25			
Mounting Board	1	1.00	1.00	50	60			
Misc. Hardware	Lot	2.50	2.50		75			
TS-6	2	.22	.44		10			
52L44	1	2.90	2.90		8			
52101A	1	3.52	3.52		8			
54LS175	1	11.00	11.00		8			
54S135	1	7.77	7.77		8			
54LS08	1	4.01	4.01		8			
5404	1	2.55	2.55		8			
LM103H	4	8.75	35.00		32			
LM107	1	4.00	4.00		8			
2N3823	1	1.50	1.50		6			
Crystal	1	1.50	1.50		15			
Coil	1	.06	.06		5			
TOTALS			129.19	50	1783 x 1.5 = 2,675			

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Transmitter

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N3415	1	.20	.20		6			
2N3866	1	.95	.95		6			
SS-3932	1	6.00	6.00		25			
SS-4006	1	26.94	26.94		25			
MM-1552	1	23.10	23.10		25			
TS-6	2	.22	.44		10			
1N457A	2	.35	.70		10			
Trim. Cap.	1	.35	.35		15			
Coils	12	.15	1.80		72			
Caps	4	.12	.48		20			
SCDM-10-xx	28	.33	9.24		140			
Resistor-Comp.	18	.03	.54		90			
Cap. F/T	2	.11	.22		16			
Misc. Hardware	Lot	5.00	5.00		200			
TOTALS			75.96		660 x 1.5 = 990			

SHEET 9 OF 12

SYSTEM VHF/IPC Duplex System-4 Channel

SUB-ASSEMBLY Logic #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
54L164	1	10.10	10.10		12			
54L93	1	10.35	10.35		12			
54L85	1	7.48	7.48		10			
CD4049	2	1.12	2.24		16			
5408	1	2.65	2.65		8			
5411	1	2.65	2.65		8			
5432	1	2.90	2.90		8			
5486	1	2.75	2.75		8			
5405	1	2.55	2.55		8			
556	1	2.05	2.05		10			
54161	2	15.98	31.96		16			
MCM6830AL	1	12.60	12.60		10			
54155	1	10.34	10.34		10			
54199	2	6.60	13.20		20			
54174	3	7.95	23.85		24			
MC14562AL	1	11.25	11.25		10			
DM7160	6	6.00	36.00		60			
Cap. Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
PC Board	1	5.00	5.00	333	485			
TOTALS			201.16	333	975 x 1.5 = 1,463			

SYSTEM VHF/IPC Duplex System-4 Channel

SUB-ASSEMBLY Logic #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	2.50	12.50		40			
54107	7	5.20	36.40		70			
5404	2	2.55	5.10		16			
5486	2	2.75	5.50		16			
5432	4	2.90	11.60		32			
5400	1	2.05	2.05		8			
5408	8	2.65	21.20		64			
Resistors	75	.03	2.25		375			
Cap. Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
TOTALS			102.21	333	1131 x 1.5 = 1,697			

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LP Filter	1	42.88	42.88		75			
Audio Trans.	1	.91	.91		75			
10mHz Crystal Filt.	2	24.18	48.36		150			
Main Chassis	1	12.00	12.00	184	44			
Front Panel		4.00	4.00	74	22			
Main Cover		5.00	5.00	288	94			
DPX Connector	1	11.97	11.97		50			
PC Connector	1	1.67	1.67		15			
Internal Wiring	Lot	2.50	2.50		500			
Misc. Hardware	Lot	6.50	6.50		350			
T/R Relay	1	5.37	5.37		75			
Misc. Conn (RU)	Lot	6.00	6.00		100			
Caps.	2	.12	.24		10			
TS-6	1	.22	.22		5			
1N4732A	1	1.30	1.30		5			
Caps. FT	2	.11	.22		16			
TOTALS			149.14	546	1586			

SHEET 12 OF 12

SYSTEM VHF/IPC Duplex System

SUB-ASSEMBLY Assembly and Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Preselector	1				50			
IF Coupler	1				25			
IF Amplifier	1				50			
Sel. Attenuator	1				50			
AGC Board	1				--			
Power Supply	1				--			
Logic Decoder	1				100			
Transmitter	1				50			
Chassis	1				250			
Power Sup Calib.					150			
Functional Test					2000			
Burn-In					1000			
TOTALS					3725			

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INVESTIGATION OF THE TECHNICAL AND OPERATIONAL FEASIBILITY OF U--ETC(U)

AUG 77 S H KOWALSKI, E R CARBONE, D A SWANN DOT-FA-76-WA-3788

UNCLASSIFIED 1326-21-01-1648-VOL-1 NL

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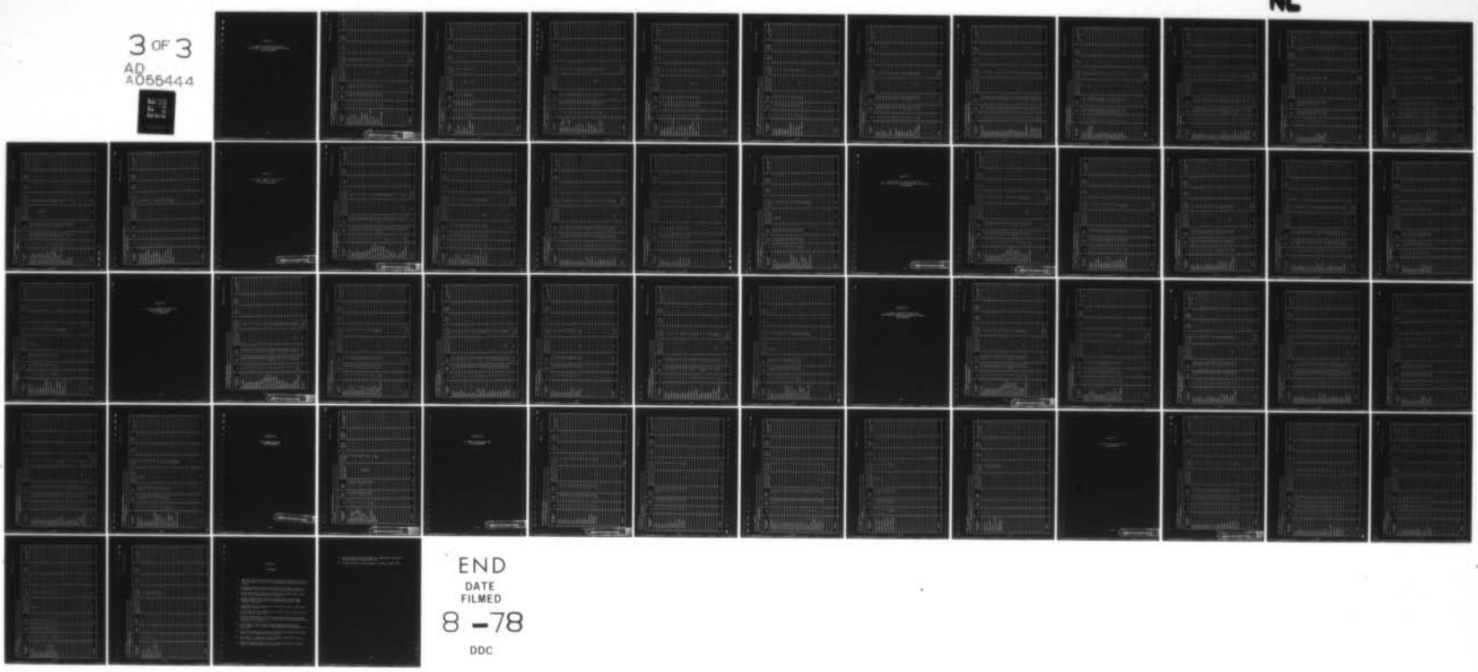

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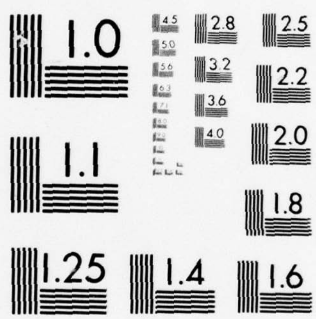

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX E-4

IPC USING A DEDICATED VHF DATA LINK, MULTI-CHANNEL (ALTITUDE DISCRIMINATING) DUPLEX, HIGH PERFORMANCE

SYSTEM VHF/IPC-Duplex-4 Channel Receiving System

SUB-ASSEMBLY Preselector

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
SMV-307	16	.50	8.00		80			
Capacitors	9	.18	1.62		45			
Tun. Coils	4	.35	1.40		60			
Resistors	7	.03	.21		35			
Coils	4	.06	.24		24			
FG Transistor	1	.90	.90		6			
Sil. Diodes	1	.21	.21		5			
Transformer	2	1.50	3.00		40			
Match Sil. Diodes	12	2.64	31.68		60			
Tun. Cap.	1	.35	.35		15			
Chassis	1	1.50	1.50	35	25			
Cover	1	.50	.50	15	10			
Misc. Hardware	Lot	.30	.30		50			
TOTALS			49.91	50	455 x 1.5 = 683			

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SHEET 2 OF 13

SYSTEM VHF/IPC-Duplex System - 4 Channel

SUB-ASSEMBLY IF Coupler

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Coils	2	.06	.12		12			
Var. Caps	2	.35	.70		30			
Cap.	1	.18	.18		5			
Chassis	1	.50	.50	30	15			
Cover	1	.15	.15	15	10			
Misc. Hardware	Lot	.25	.25		25			
P.C. Board	1	.75	.75	35	15			
TOTALS			2.65	80	112 x 1.5 = 168			

SYSTEM VHF/IPC Duplex System - 4 Channel

SUB-ASSEMBLY IF Amp.

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N4997 (MFS	1	.40	.40		6			
2N3688 6588A)	2	.27	.54		12			
2N3906	2	.33	.66		12			
997F-17 TMTK	1	.76	.76		5			
1N270	2	.13	.26		10			
1N816	1	.35	.35		5			
VHR-Caps	3	.35	1.05		45			
Caps. Disc	22	.12	2.64		110			
Cap Trnt.	1	.18	.18		5			
Coils	5	.06	.30		30			
Coil-Typed	1	.35	.35		15			
Resistors	21	.03	.63		105			
Chassis	1	1.25	1.25	75	50			
Cover	1	.35	.35	15	15			
Misc. Hardware	Lot	1.50	1.50		50			
Cap. - F/T	7	.11	.77		56			
TOTALS			11.99	90	531 x 1.5 = 797			

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Selectable Attenuator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MPS-H10	2	.33	.66		12			
MPSA 56	1	.37	.37		6			
SMV-307	1	.50	.50		6			
5082-2811	2	.63	1.26		10			
Tun. Coil (3 pd)	1	.35	.35		15			
Coils	2	.06	.12		12			
Cap. T/M	2	.18	.36		10			
Cap. Disc.	9	.12	1.08		45			
Resistors	12	.03	.36		60			
Cap. F/T	3	.11	.33		24			
P.C. Board	1	.45	.45	45	50			
Chassis Housing	1	.40	.40	60	40			
Cover	1	.20	.20	15	10			
Misc. Hardware	Lot	.85	.85		45			
TOTAL			7.29	120	345 x 1.5 = 518			

SHEET 5 OF 13

SYSTEM VHF/IPC-Duplex-4 Channel Receiving System

SUB-ASSEMBLY

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N2925	1	.22	.22		6			
2N3702	1	.32	.32		6			
2N3906	1	.34	.34		6			
2N3403	1	.32	.32		6			
1N816	1	.25	.25		5			
997F-17	1	.76	.76		5			
Potentiometer	2	.65	1.30		30			
Cap - T/M	6	.18	1.08		30			
Resistors	19	.03	.57		95			
Mtg. Board	1	.75	.75	50	75			
Misc. Hardware	Lot	1.25	1.25		50			
TOTALS			7.16	50	314 x 1.5 = 471			

SYSTEM VHF/IPC Duplex-4 Channel Receiving System

SUB-ASSEMBLY Freq. Control

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
93406	1	14.00	14.00		10			
5406	1	5.30	5.30		8			
CD 4049	2	1.12	2.24		16			
54L74	4	4.20	16.80		32			
556	1	2.05	2.05		10			
111457A	7	.35	2.45		35			
	19	.12	2.28		95			
Resistors	52	.03	1.56		260			
1N4148	1	.13	.13		5			
2N3823	8	.78	6.24		48			
54H52	2	2.05	4.10		16			
LM107	8	4.25	34.00		80			
Crystals	8	1.50	12.00		120			
Coils	8	.06	.48		48			
P.C. Board	1	2.50	2.50	333	485			
Misc. Hardware	Lot	1.00	1.00		50			
TOTALS			107.13	333	1318 x 1. = 1318			

SYSTEM VHF/IPC-Duplex-4 channel

SUB-ASSEMBLY Power Supply-Modulator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
ON-OFF Relay	1	4.54	4.45		15			
2N3440	1	.75	.75		6			
2N3417	2	.30	.60		12			
2N4917	3	.21	.63		18			
2N3789	1	2.45	2.45		6			
2N4871	1	.45	.45		6			
2N3415	3	.20	.60		18			
2N5322	1	1.02	1.02		6			
2N4923	2	.79	1.58		12			
2N4399	1	5.40	5.40		6			
1N5344B	1	1.67	1.67		5			
1N4735A	1	1.30	1.30		5			
1N4934	2	.35	.70		10			
1N942A	1	3.00	3.00		5			
1N457A	2	.29	.58		10			
1N816	1	.35	.35		5			
Potentiometer	2	1.30	2.60		30			
Coils	4	.06	.24		24			
Cap. Elect.	3	1.55	4.65		45			
Cap.-Tant.	8	.18	1.44		40			
Cap.-Disc.	15	.12	1.80		75			
Resistors	62	.03	1.86		310			

SYSTEM VHF/IPC-Duplex-4 Channel

SUB-ASSEMBLY Power Supply-Modulator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Toroids	2	6.21	12.42		830			
Fuse-2A	1	.81	.81		25			
Mounting Bd.	1	1.00	1.00	50	60			
Misc. Hardware	Lot	2.50	2.50		75			
TS-6	2	.22	.44		10			
52L44	1	2.90	2.90		8			
52101A	1	3.52	3.52		8			
54LS175	1	11.00	11.00		8			
54S135	1	7.77	7.77		8			
54LS08	1	4.01	4.01		8			
5404	1	2.55	2.55		8			
LM103H	4	8.75	35.00		32			
LM107	1	4.00	4.00		8			
2N3823	1	1.50	1.50		6			
Crystal	1	1.50	1.50		15			
Coil	1	.06	.06		5			
TOTALS			129.63	50	1783 x 1.5 = 2675			

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Logic #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
54L164	1	10.10	10.10		12			
54L93	1	10.35	10.35		12			
54L85	1	7.48	7.48		10			
CD4049	2	1.12	2.24		16			
5408	1	2.65	2.65		8			
5411	1	2.65	2.65		8			
5432	1	2.90	2.90		8			
5486	1	2.75	2.75		8			
5405	1	2.55	2.55		8			
556	1	2.05	2.05		10			
54161	2	15.98	31.96		16			
MCM6830AL	1	12.60	12.60		10			
54155	1	10.34	10.34		10			
54199	2	6.60	13.20		20			
54174	3	7.95	23.85		24			
MC14562AL	1	11.25	11.25		10			
DM7160	6	6.00	36.00		60			
Cap-Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
P.C. Board	1	5.00	5.00	333	485			
TOTALS			195.16	333	975 x 1.5 = 1463			

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Logic #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	2.50	12.50		40			
54107	7	5.20	36.40		70			
5404	2	2.55	5.10		16			
5486	2	2.75	5.50		16			
5432	4	2.90	11.60		32			
5400	1	2.05	2.05		8			
5408	8	2.65	21.20		64			
Resistors	75	.03	2.25		375			
Cap-Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
P.C. Board	1	5.00	5.00	333	485			
TOTALS			102.21	333	1131 x 1.5 = 1697			

SHEET 11 OF 13

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Transmitter

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N3415	1	.20	.20		6			
2N3866	1	.95	.95		6			
SS-3932	1	6.00	6.00		25			
SS-4006	1	26.94	26.94		25			
MM-1552	1	23.10	23.10		25			
TS-6	2	.22	.44		10			
1N457A	2	.35	.70		10			
Trim. Cap	1	.35	.35		15			
Coils	12	.15	1.80		72			
Caps	4	.12	.48		20			
SCDM-10-XX	28	.33	9.24		140			
Resistor Comp.	18	.03	.54		90			
Cap. F/T	2	.11	.22		16			
Misc. Hardware	Lot	5.00	5.00		200			
TOTALS			75.96		660 x 1.5 = 990			

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LP Filter	1	42.88	42.88		75			
Audio Trans.	1	.91	.91		75			
BP Filters	2	24.18	48.36		150			
Main Chassis	1	12.00	12.00	184	44			
Front Panel		4.00	4.00	74	22			
Main Cover		5.00	5.00	288	94			
DPX Connector	1	11.97	11.97		50			
PC Connector	1	1.67	1.67		15			
Internal Wiring	Lot	2.50	2.50		500			
Misc. Hardware	Lot	6.50	6.50		350			
T/R Relay	1	5.37	5.37		75			
Misc. Conn. (RU)	Lot	6.00	6.00		100			
Caps	2	.12	.24		10			
TS-6	1	.22	.22		5			
1N4732A	1	1.30	1.30		5			
Caps FT	2	.11	.22		16			
TOTAL			149.14	546	1586			

SYSTEM VHF/IPC-Duplex System-4 Channel

SUB-ASSEMBLY Assembly & Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Preselector	1				50			
IF Coupler	1				25			
IF Amplifier	1				50			
Sel. Attenuator	1				50			
AGC Board	1				-			
Power Supply	1				-			
Logic Decoder	1				100			
Transmitter	1				50			
Chassis	1				250			
Freq. Control	1				100			
Pwr. Sup. Calib.					150			
Functional Test					2000			
Burn-In					1000			
TOTALS					3825			

APPENDIX E-5

IPC USING A DEDICATED VHF DATA LINK,
SINGLE CHANNEL, UPLINK ONLY
LOS PERFORMANCE,

SHEET 1 OF 5

SYSTEM VHF/IPC-Receiving Only-GA

SUB-ASSEMBLY Receiver Module

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
FET, Mixer	2	1.20	2.40		6			
2N3391	3	.36	1.08		18			
MC1330P	1	1.15	1.15		8			
MC1349P	1	.90	.90		8			
2N5356	1	.35	.35		6			
MC3401P	1	.64	.64		8			
Veractor	7	.50	3.50		35			
Si. Diode	1	.22	.22		5			
Coil, Tunable	7	.35	2.45		40			
Coil, Fixed 51d	1	.15	.15		15			
6 pole filter	1	15.00	15.00		15			
4 pole filter	1	10.00	10.00		15			
Cap. Variable	3	.18	.54		45			
Cap. Disc	31	.12	3.72		155			
Resistors	43	.03	1.29		215			
Crystal	1	1.00	1.00		15			
2N3823	1	.78	0.78		6			
Coil	1	.06	.06		6			
LM107	1	2.65	2.65		8			
PC Board	1	3.00	3.00	333	485			
Misc Hardware	Lot	.50	.50		50			
Totals			51.38	333	1164 x 1.4 = 1,630			

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SYSTEM VHF/IPC-Receiving Only-GA

SUB-ASSEMBLY Leveling Board/Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N5356	2	.35	.70		12			
2N3391	2	.36	.72		12			
Diode, Sil	4	.22	.88		20			
8.2V Zener	1	.43	.43		5			
2N5810	1	.32	.32		6			
2N5811	1	.32	.32		6			
MC7808 1C	1	1.15	1.15		8			
MC7805 1C	1	1.05	1.05		8			
Cap. T/E	7	.18	1.26		35			
Cap. Disc/M	7	.12	.84		35			
Resistors	19	.03	.57		95			
L201 Power Choke	1	.95	.95		415			
PC Board	1	3.00	3.00	333	485			
Misc Hardware	Lot	.50	.50		75			
Totals			12.69	333	1217 x 1.5 = 1,826			

SHEET 3 OF 5

SYSTEM VHF/IPC-Receiving Only-GA

SUB-ASSEMBLY Logic Decoder #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74L164	1	1.35	1.35		12			
74L93	1	.71	.71		12			
74L85	1	1.68	1.68		10			
CD4049	2	.93	1.86		16			
7408	1	.33	.33		8			
7411	1	.33	.33		8			
7432	1	.44	.44		8			
7486	1	.50	.50		8			
7405	1	.38	.38		8			
Cap. Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	.96	.96		10			
74161	2	2.19	4.38		16			
MCM6830	1	8.15	8.15		10			
74155	1	1.28	1.28		10			
74199	2	3.25	6.50		20			
DM8160	6	2.56	15.36		60			
74174	3	1.88	5.64		24			
PC Board	1	5.00	5.00	333	485			
Totals			61.21	333	965 x 1.5 = 1,448			

SYSTEM VHF/IPC-Receiving Only-GA

SUB-ASSEMBLY Logic Decoder #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	1.50	7.50		40			
74107	7	.48	3.36		70			
7404	2	.38	.76		16			
7486	2	.50	1.00		16			
7432	4	.44	1.76		32			
7400	1	.30	.30		8			
7408	8	.33	2.64		64			
Resistors	75	.03	2.25		375			
Cap. Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
Totals			25.18	333	1131 x 1.5 = 1,697			

SYSTEM VHF/IPC-Receiving Only-GA

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Face Plate	1	2.00	2.00	74	50			
Chassis	1	1.75	1.75	184	75			
Cover	1	1.00	1.00	82	40			
Switch	1	.65	.65		15			
Lamps	9	.08	.72		45			
Holder	9	.10	.90		90			
Connector-Cable	1	1.15	1.15		50			
Connector-RF	1	.85	.85		25			
Connector-PC	4	.35	1.40		100			
Wiring	Lot	1.00	1.00		500			
Misc. Hardware	Lot	3.00	1.00		250			
Final Assbly					400			
Burn-In					1000			
Functional Test					500			
Totals			12.42	340	3140			

APPENDIX E-6

IPC USING A DEDICATED VHF DATA LINK,
MULTI-CHANNEL (ALTITUDE DISCRIMINATING), UPLINK ONLY,
LOW PERFORMANCE

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SHEET 1 OF 6

SYSTEM VHF/IPC-4 CHannel Receiving - GA

SUB-ASSEMBLY Receiver Module

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Fet. Mixer	2	1.20	2.40		6			
2N3391	3	.36	1.08		18			
MC1330P	1	1.15	1.15		8			
MC1349P	1	.90	.90		8			
2N5356	1	.35	.35		6			
MC3401P	1	.64	.64		8			
Veractor	7	.50	3.50		35			
Si. Diode	1	.22	.22		5			
Coil, Tunable	7	.35	2.45		42			
Coil, Fixed 5Pd	1	.15	.15		10			
6 Pole Filter	1	15.00	15.00		15			
4 Pole Filter	1	10.00	10.00		15			
Cap. Variable	3	.18	.54		45			
Cap - Disc	30	.12	3.60		150			
Resistors	37	.03	1.11		185			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		50			
TOTALS			46.59	333	1091 x 1.4 = 1527			

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SYSTEM VHF/IPC - 4 Channel Receiving - GA

SUB-ASSEMBLY Leveling Board/Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N5356	2	.35	.70		12			
2N3391	2	.36	.72		12			
Diode Sil.	4	.22	.88		20			
8.2V Zener	1	.43	.43		5			
2N5810	1	.32	.32		6			
2N5811	1	.32	.32		6			
MC7808 1C	1	1.15	1.15		8			
MC7805 1C	1	1.05	1.05		8			
Cap-T/E	7	.18	1.26		35			
Cap-Disc	7	.12	.84		35			
Resistors	19	.03	.57		95			
Power Choke	1	.95	.95		415			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		75			
TOTALS			12.69	333	1217 x 1.5 = 1826			

SYSTEM VHF/IPC-4 Channel Receiving - GA

SUB-ASSEMBLY Frequency Control

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
93406	1	13.20	13.20		10			
7406	1	.86	.86		8			
CD4049	2	.93	1.86		16			
74L74	4	.48	1.92		32			
556	1	.96	.96		10			
1N457A	7	.35	2.45		35			
1N4148	1	.13	.13		5			
2N3823	4	.78	3.12		24			
74H52	1	.36	.36		8			
LM207	4	2.35	9.40		40			
Caps-Disc	15	.12	1.80		75			
Resistors	44	.03	1.32		220			
Crystals	4	1.00	4.00		60			
Coils	4	.06	.24		24			
PC Board	1	2.50	2.50	333	485			
Misc. Hardware	Lot	1.00	1.00		50			
TOTALS			45.12	333	1102 x 1. = 1102			

SYSTEM VHF/IPC-4 Channel Receiving - GA

SUB-ASSEMBLY Logic Decoder #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74L164	1	1.35	1.35		12			
74L93	1	.71	.71		12			
74L85	1	1.68	1.68		10			
CD4049	2	.93	1.86		16			
7408	1	.33	.33		8			
7411	1	.33	.33		8			
7432	1	.44	.44		8			
7486	1	.50	.50		8			
7405	1	.38	.38		8			
Cap-Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	.96	.96		10			
74161	2	2.19	4.38		16			
MCM6830	1	8.15	8.15		10			
74155	1	1.28	1.28		10			
74199	2	3.25	6.50		20			
DM8160	6	2.56	15.36		60			
74174	3	1.88	5.64		24			
PC Board	1	5.00	5.00	333	485			
TOTALS			61.21	333	965 x 1.5 = 1448			

SHEET 5 OF 6

SYSTEM VHF/IPC-4 Channel Receiving-GA

SUB-ASSEMBLY Logic Decoder #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	1.50	7.50		40			
74107	7	.48	3.36		70			
7404	2	.38	.76		16			
7486	2	.50	1.00		16			
7432	4	.44	1.76		32			
7400	1	.30	.30		8			
7408	8	.33	2.64		64			
Resistors	75	.03	2.25		375			
Cap-Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
TOTALS			25.18	333	1131 x 1.5 = 1697			

SYSTEM VHF/IPC-4 Channel Receiving-GA

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Face Plate	1	2.00	2.00	74	50			
Chassis	1	1.75	1.75	184	75			
Cover	1	1.00	1.00	82	40			
Switch	1	.65	.65		15			
Lamps	9	.08	.72		45			
Holders	9	.10	.90		90			
Connector-Cable	1	1.15	1.15		50			
Connector-RF	1	.85	.85		25			
Connector-PC	5	.35	1.75		125			
Wiring	Lot	1.15	1.15		500			
Misc. Hardware	Lot	1.15	1.15		250			
Final Assldy.					400			
Burn-In					1000			
Functional Test					500			
TOTALS			13.07	340	3165			

APPENDIX E-7

IPC USING A DEDICATED VHF DATA LINK,
SINGLE CHANNEL DUPLEX,
LOW PERFORMANCE

SHEET 1 OF 6

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Receiver Module

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
FET, Mixer	2	1.20	2.40		6			
2N3391	3	.36	1.08		18			
MC1330P	1	1.15	1.15		8			
MC1349P	1	.90	.90		8			
2N5356	1	.35	.35		6			
MC3401P	1	.64	.64		8			
Veractor	7	.50	3.50		35			
Si. Diode	1	.22	.22		5			
Coil, Tunable	7	.35	2.45		40			
Coil, Fixed 51d	1	.15	.15		15			
6 pole filter	1	15.00	15.00		15			
4 pole filter	1	10.00	10.00		15			
Cap. Variable	3	.18	.54		45			
Cap. Disc	31	.12	3.72		155			
Resistors	43	.03	1.29		215			
Crystal	2	1.00	2.00		30			
2N3823	2	.78	1.56		12			
Coils	2	.06	.12		12			
LM107	2	2.65	5.30		16			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		50			
Totals			55.87	333	1199 x 1.4 = 1,679			

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Leveling Board/Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N5356	2	.35	.70		12			
2N3391	2	.36	.72		12			
Diode, Sil	4	.22	.88		20			
8.2V Zener	1	.43	.43		5			
2N5810	1	.32	.32		6			
2N5811	1	.32	.32		6			
MC7808 1C	1	1.15	1.15		8			
MC7805 1C	1	1.05	1.05		8			
Cap. T/E	7	.18	1.26		35			
Cap. Disc	7	.12	.84		35			
Resistors	19	.03	.57		95			
Power Choke	1	.95	.95		415			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		75			
Totals			12.69	333	1217 x 1.5 = 1,826			

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Logic Decoder #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74L164	1	1.35	1.35		12			
74L93	1	.71	.71		12			
74L85	1	1.68	1.68		10			
CD4049	2	.93	1.86		16			
7408	1	.33	.33		8			
7411	1	.33	.33		8			
7432	1	.44	.44		8			
7486	1	.50	.50		8			
7405	1	.38	.38		8			
Cap. Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	.96	.96		10			
74161	2	2.19	4.38		16			
MCM6830	1	8.15	8.15		10			
74155	1	1.28	1.28		10			
74199	2	3.25	6.50		20			
DM8160	6	2.56	15.36		60			
74174	3	1.88	5.64		24			
PC Board	1	5.00	5.00	333	485			
MC14562	1	6.25	6.25		10			
Totals			67.46	333	975 x 1.5 = 1,463			

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Logic Decoder #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	1.50	7.50		40			
74107	7	.48	3.36		70			
7404	2	.38	.76		16			
7486	2	.50	1.00		16			
7432	4	.44	1.76		32			
7400	1	.30	.30		8			
7408	8	.33	2.64		64			
Resistors	75	.03	2.25		375			
Cap. Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
Totals			25.18	333	1131 x 1.5 = 1,697			

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Transmitter/Modulator

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74LS175	1	1.64	1.64		8			
LM201	8	.80	6.40		64			
74LS174	1	1.88	1.88		8			
74S135	1	1.65	1.65		8			
74LS08	1	.33	.33		8			
7404	1	.38	.38		8			
1N747A	4	.43	1.72		20			
LM207	1	2.35	2.35		8			
2N3823	1	.78	.78		6			
Crystal	1	1.00	1.00		15			
Resistor	36	.03	1.08		180			
Capacitors	26	.12	3.12		130			
Coil	2	.06	.12		12			
2N5016	1	11.75	11.75		6			
2N5590	1	5.50	5.50		6			
2N3866	2	.95	1.90		12			
1N4005	2	.45	.90		10			
Coil-Fixed	10	.35	3.50		100			
PC Board	1	5.00	5.00	333	485			
Misc. Hardware	Lot	1.50	1.50		100			
Totals			52.50	333	1194 x 1.5 = 1,791			

SYSTEM VHF/IPC-Duplex-GA

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Face Plate	1	2.00	2.00	74	50			
Chassis	1	2.00	2.00	184	85			
Cover	1	1.00	1.00	82	40			
Switch	1	.65	.65		15			
Lamps	9	.08	.72		45			
Holder	9	.10	.90		90			
Connector-Cable	1	1.15	1.15		50			
Connector-RF	3	.85	2.55		75			
Connector-PC	5	.35	1.75		125			
T/R Relay	1	1.75	1.75		75			
Wiring	Lot	1.25	1.25		600			
Misc. Hardware	Lot	4.00	4.00		300			
Final Assbly					500			
Burn-In					1000			
Functional Test					1000			
Totals			19.72	340	4050			

APPENDIX E-8

IPC USING A DEDICATED VHF DATA LINK,
MULTI-CHANNEL (ALTITUDE DISCRIMINATING) DUPLEX,
LOW PERFORMANCE

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Receiver Module

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
FET, Mixer	2	1.20	2.40		6			
2N3391	3	.36	1.08		18			
MC1330P	1	1.15	1.15		8			
MC1349P	1	.90	.90		8			
2N5356	1	.35	.35		6			
MC3401P	1	.64	.64		8			
Veractor	7	.50	3.50		35			
Si. Diode	1	.22	.22		5			
Coil, Tunable	7	.35	2.45		42			
Coil, Fixed 51d	1	.15	.15		10			
6 pole filter	1	15.00	15.00		15			
4 pole filter	1	10.00	10.00		15			
Cap. Variable	3	.18	.54		45			
Cap. Disc	30	.12	3.60		150			
Resistor	37	.03	1.11		185			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		50			
Totals			46.59	333	1091 x 1.4 = 1,527			

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Leveling Board/Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N5356	2	.35	.70		12			
2N3391	2	.36	.72		12			
Si. Diode	4	.22	.88		20			
8.2V Zener	1	.43	.43		5			
2N5810	1	.32	.32		6			
2N5811	1	.32	.32		6			
MC7808	1	1.15	1.15		8			
MC7805	1	1.05	1.05		8			
Cap. T/E	7	.18	1.26		35			
Cap. Disc	7	.12	.84		35			
Resistor	19	.03	.57		95			
Power Choke	1	.95	.95		415			
PC Board	1	3.00	3.00	333	485			
Misc. Hardware	Lot	.50	.50		75			
TOTALS			12.69	333	1217 x 1.5 = 1,826			

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Frequency Control

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
93406	1	13.20	13.20		10			
7406	1	.86	.86		8			
CD4049	2	.93	1.86		16			
74L74	4	.48	1.92		32			
556	1	.96	.96		10			
1N457A	7	.35	2.45		35			
1N4148	1	.13	.13		5			
2N3823	8	.78	6.24		48			
74H52	2	.36	.72		16			
LM207	8	2.35	18.80		80			
Cap. Disc	19	.12	2.28		95			
Resistor	52	.03	1.56		260			
Crystals	8	1.00	8.00		120			
Coils	8	.06	.48		48			
PC Board	1	2.50	2.50	333	485			
Misc. Hardware	Lot	1.00	1.00		50			
TOTALS			62.96	333	1318 x 1 = 1,318			

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Logic #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74L164	1	1.35	1.35		12			
74L93	1	.71	.71		12			
74L85	1	1.68	1.68		10			
CD4049	2	.93	1.86		16			
7408	1	.33	.33		8			
7411	1	.33	.33		8			
7432	1	.44	.44		8			
7486	1	.50	.50		8			
7405	1	.38	.38		8			
Cap. Disc	12	.12	1.44		60			
1N457A	12	.35	4.20		60			
Resistors	24	.03	.72		120			
556	1	.96	.96		10			
74161	2	2.19	4.38		16			
MCM6830	1	8.15	8.15		10			
74155	1	1.28	1.28		10			
74199	2	3.25	6.50		20			
DM8160	6	2.56	15.36		60			
74174	3	1.88	5.64		24			
PC Board	1	5.00	5.00	333	485			
MC14562	1	6.25	6.25		10			
TOTALS			67.46	333	975 x 1.5 = 1,463			

SHEET 5 OF 7

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Logic #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
55453B	5	1.50	7.50		40			
74107	7	.48	3.36		70			
7404	2	.38	.76		16			
7486	2	.50	1.00		16			
7432	4	.44	1.76		32			
7400	1	.30	.30		8			
7408	8	.33	2.64		64			
Resistors	75	.03	2.25		375			
Cap. Disc	4	.12	.48		20			
1N4148	1	.13	.13		5			
PC Board	1	5.00	5.00	333	485			
TOTALS			25.18	333	1131 x 1.5 = 1,697			

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Transmitter/Modulation

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
74LS175	1	1.64	1.64		8			
LM201	8	.80	6.40		64			
74LS174	1	1.88	1.88		8			
74S135	1	1.65	1.65		8			
74LS08	1	.33	.33		8			
7404	1	.38	.38		8			
1N747A	4	.43	1.72		20			
LM207	1	2.35	2.35		8			
2N3823	1	.78	.78		6			
Crystal	1	1.00	1.00		15			
Resistor	36	.03	1.08		180			
Capacitors	26	.12	3.12		130			
Coil	2	.06	.12		12			
2N5016	1	11.75	11.75		6			
2N5590	1	5.50	5.50		6			
2N3866	2	.95	1.90		12			
1N4005	2	.45	.90		10			
Coil-Fixed	10	.35	3.50		100			
PC Board	1	5.00	5.00	333	485			
Misc. Hardware	Lot	1.50	1.50		100			
TOTALS			52.50	333	1194 x 1.5 = 1,791			

SYSTEM VHF/IPC-4 Channel Duplex-GA

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Face Plate	1	2.00	2.00	74	50			
Chassis	1	2.00	2.00	184	85			
Cover	1	1.00	1.00	82	40			
Switch	1	.65	.65		15			
Lamps	9	.08	.72		45			
Holder	9	.10	.90		90			
Connector-Cable	1	1.15	1.15		50			
Connector-RF	3	.85	2.55		75			
Connector-PC	6	.35	2.10		150			
T/R Relay	1	1.75	1.75		75			
Wiring	Lot	1.50	1.50		650			
Misc. Hardware	Lot	4.00	4.00		300			
Final Assbly					500			
Burn-In					1000			
Functional Test					1000			
TOTALS			20.32	340	4125			

APPENDIX E-9

IPC COMMAND INDICATOR,
HIGH PERFORMANCE

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SHEET ______ OF ______

SYSTEM IPC Command Indicator

SUB-ASSEMBLY ______

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LED	8	.22	1.76		40			
Lamp Holders	8	.20	1.60		40			
Switch - PB	1	1.35	1.35		15			
Switch - Toggle	1	.64	.64		15			
Connector-MS	1	15.00	15.00		200			
Face Plate	1	2.00	2.00	200	25			
Chassis	1	1.50	1.50	125	50			
Cover	1	1.00	1.00	100	50			
Misc. Hardware	Lot	1.50	1.50					
Assembly	-				170			
Test	-				1000			
TOTALS			26.35	425	1605			

APPENDIX E-10

IPC USING THE ACARS DATA LINK, HIGH PERFORMANCE

SHEET 1 OF 5

SYSTEM ACARS/IPC Interface

SUB-ASSEMBLY Logic Board #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
5400	2	.85	1.70		16			
5404	1	1.06	1.06		8			
5408	6	.85	5.10		48			
5430	1	.92	.92		8			
5432	3	1.15	3.45		24			
5437	3	1.33	3.99		24			
5486	1	1.62	1.62		8			
54107	2	1.33	2.66		16			
54155	1	5.97	5.97		10			
54157	4	3.20	12.80		40			
54164	4	3.87	15.48		32			
Capacitors	2	.12	.24		10			
Resistors	35	.03	1.05		175			
PC Board	1	5.00	5.00	333	485			
TOTALS			61.04	333	904 x 1.5 = 1356			

SYSTEM ACARS/IPC

SUB-ASSEMBLY Logic Board #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
54166	14	7.38	103.32		140			
54174	3	3.63	10.89		30			
9316	2	4.06	8.12		20			
9616	2	4.88	9.76		16			
9617	2	1.86	3.72		16			
55453B	5	1.50	7.50		40			
NE556	2	2.05	4.10		16			
IN4148	1	.13	.13		5			
Capacitors	3	.12	.36		15			
Resistors	40	.03	1.20		200			
PC Board	1	5.00	5.00	333	485			
TOTALS			154.10	333	983 x 1.5 = 1475			

SHEET 3 OF 5

SYSTEM ACARS/IPC

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Transformer	1	17.35	17.35		615			
MC1569 G	1	4.50	4.50		10			
Mc1563 G	1	5.25	5.25		10			
2N 4911	1	.95	.95		5			
2N 5089	1	.27	.27		5			
2N 4899	1	1.10	1.10		5			
2N 5086	1	.21	.21		5			
2N 3055	1	.90	.90		5			
1N 4003	7	.13	.91		35			
1N 4720	2	.75	1.50		10			
1N 457A	1	.19	.19		5			
1N 4733A	1	.60	.60		5			
MR 1120	2	.77	1.54		10			
Cap-T	10	.18	1.80		50			
Cap Disc.	3	,12	.36		15			
Potentiometer	2	.35	.70		30			
Resistor	6	.03	.18		30			
Fuse/Holder	1	.65	.65		15			
PC Board	1	4.00	4.00	333	485			
TOTALS			42.96	333	1355			

SYSTEM ACARS/IPC

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Main Chassis	1	8.00	8.00	184	44			
Front Panel	1	2.00	2.00	74	22			
Main Cover	1	2.50	2.50	288	94			
PC Connection	3	1.67	5.01		45			
DPA Connector	1	11.97	11.97		50			
Int. Wiring	Lot	1.50	1.50		250			
Misc. Hardware	Lot	4.50	4.50		250			
TOTALS			35.48	546	755			

SHEET 5 OF 5

SYSTEM ACARS/IPC

SUB-ASSEMBLY Final Assembly and Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Logic #1	1				10			
Logic #2	1				10			
Power Supply	1				100			
Chassis	1				250			
Functional Test					1000			
Burn-In					1000			
Power Supply Calibration					150			
TOTALS					2520			

APPENDIX E-11

IPC USING THE ACARS DATA LINK,
LOW PERFORMANCE

SHEET 1 OF 5

SYSTEM MINI ACARS

SUB-ASSEMBLY Logic #1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
7400	2	.35	.70		16			
7404	4	.43	1.72		32			
7408	7	.37	2.59		56			
7417	1	1.80	1.80		8			
7420	1	.35	.35		8			
74H21	2	.35	.70		16			
7425	5	.50	2.50		40			
7430	4	.35	1.40		32			
7432	1	.49	.49		8			
7486	3	.56	1.68		24			
2N3403	1	.25	.25		6			
2N3823	1	.78	.78		6			
1N4148	1	.18	.18		5			
Capacitor	4	.12	.48		20			
Inductor	3	.12	.36		15			
Resistors	24	.03	.72		120			
PC Board	1	5.00	5.00	333	485			
TOTALS			21.70	333	897 x 1.5 = 1346			

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SYSTEM MINI ACARS

SUB-ASSEMBLY Logic #2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
7473	10	1.30	13.00		80			
74150	3	2.70	8.10		36			
74151A	1	.99	.99		10			
74155	1	.99	.99		10			
74157	1	.80	.80		10			
74174	3	1.42	4.26		30			
74177	3	1.07	3.21		24			
74199	4	2.49	9.96		48			
74260	1	.27	.27		8			
LM310	2	2.75	5.50		16			
LM311	1	.86	.86		8			
MM6341-1	2	13.65	27.30		40			
556	1	.96	.96		10			
Crystal 4mHz	1	5.00	5.00		15			
Capacitor	2	.12	.24		10			
Inductor	1	.18	.18		5			
Resistors	30	.03	.90		150			
PC Board	1	5.00	5.00	333	485			
TOTALS			87.52	333	995 x 1.5 = 1493			

SHEET 3 OF 5

SYSTEM MINI ACARS

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MA723	1	1.95	1.95		8			
2N2450	1	1.05	1.05		6			
2N3879	1	1.90	1.90		6			
2N5322	1	1.02	1.02		6			
1N967A	1	.40	.40		5			
1N5416	1	.40	.40		5			
1N963B	1	.40	.40		5			
1N5552	1	2.25	2.25		5			
Coil	3	.12	.36		15			
Cap-T	7	.18	1.26		35			
Cap. Disc	4	.12	.48		20			
PC Board	1	3.00	3.00	333	485			
TOTALS			14.47	333	601			

SYSTEM MINI ACARS

SUB-ASSEMBLY Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Face Plate	1	2.00	2.00	74	50			
Chassis	1	2.00	2.00	184	85			
Cover	1	1.00	1.00	82	40			
Switch	1	.65	.65		15			
Lamps	9	.08	.72		45			
Holder	9	.10	.90		90			
Thumbwheel Sw.	1	4.50	4.50		25			
Connector, Cable	1	1.15	1.15		50			
Connector, PC	3	.35	1.05		75			
Wiring	Lot	1.00	1.00		450			
TOTALS			14.97	340	925			

SHEET 5 OF 5

SYSTEM MINI ACARS

SUB-ASSEMBLY Assembly & Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAILURE RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Logic #1	1				10			
Logic #2	1				10			
Power Supply	1				100			
Chassis	1				250			
Pwr. Sup. Calib					150			
Functional Test					500			
Burn-in					1000			
TOTALS					2020			

APPENDIX F

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